Precipitation Strengthenable NiTiPd High Temperature Shape Memory Alloys

Glen Bigelow,[1] Anita Garg,[2] Othmane Benafan,[1] Ronald Noebe,[1]
Darrell Gaydosh,[3] and Santo Padula II[1]

[1]NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135
[2]University of Toledo, Toledo, OH 43606
[3]Ohio Aerospace Institute, Cleveland, OH 44142

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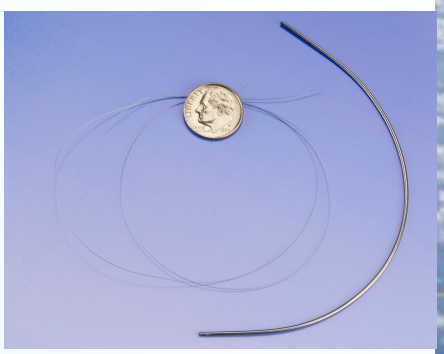
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

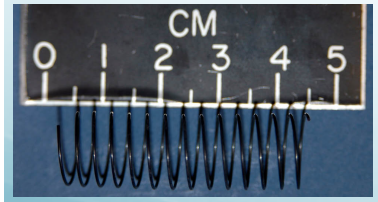
Opportunities for SMA Actuators

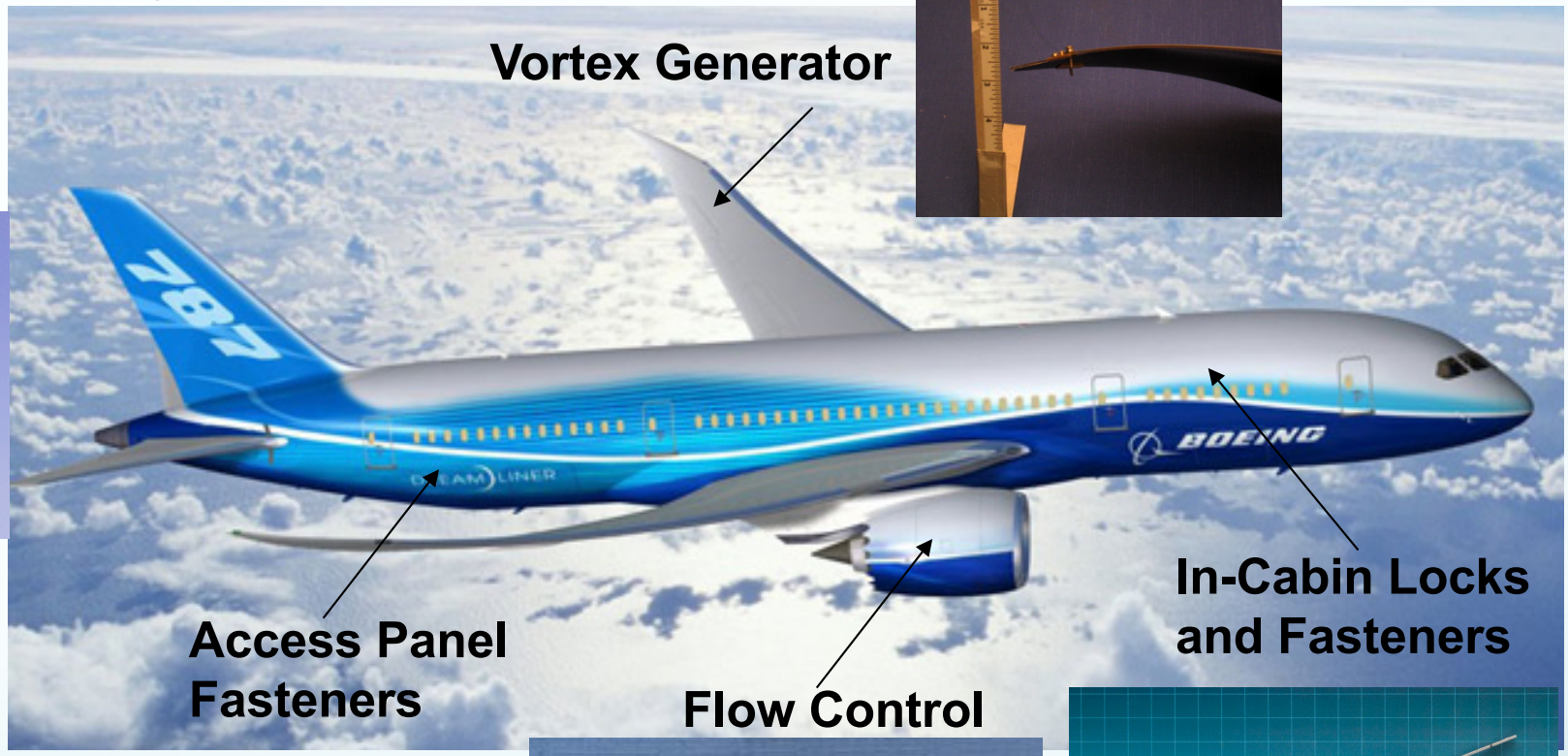
NiTiPd is expensive
=> Actuators most likely wire based

Can be drawn to fine wire



Shape set to form springs, etc.



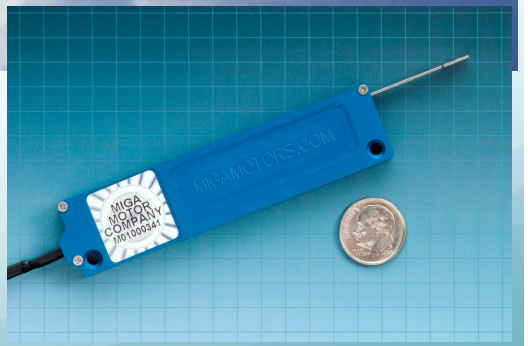


Vortex Generator

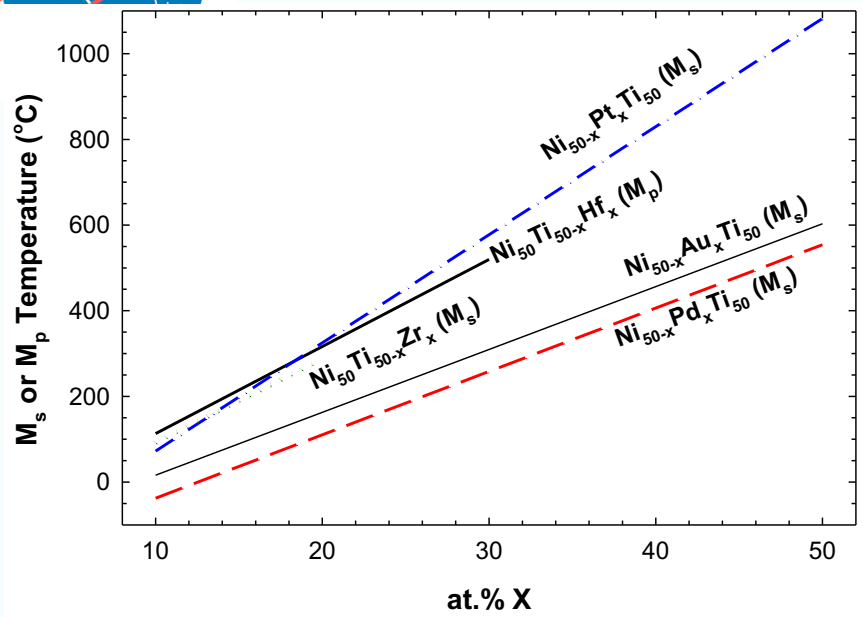
Access Panel Fasteners

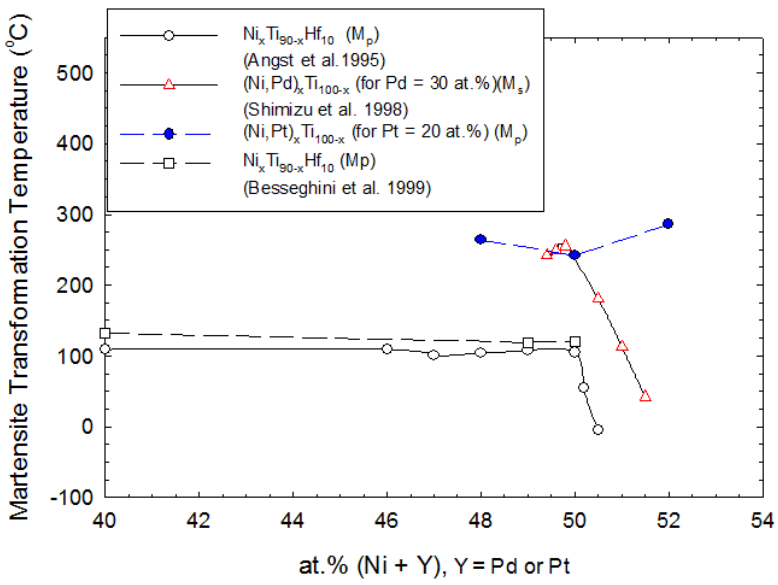
Flow Control

In-Cabin Locks and Fasteners

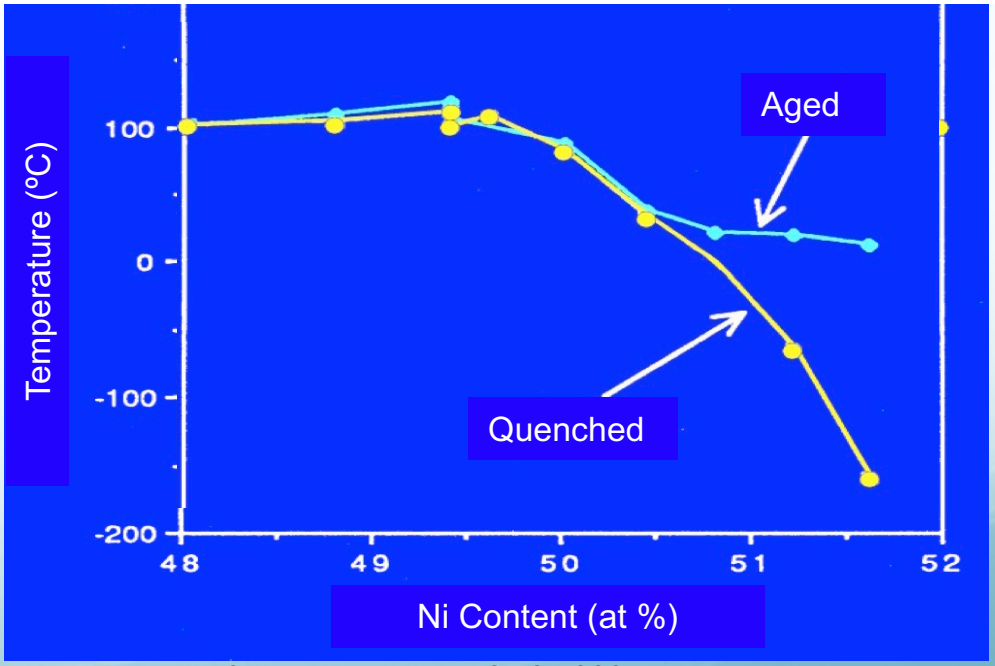


Compositional Control is IMPORTANT!!!





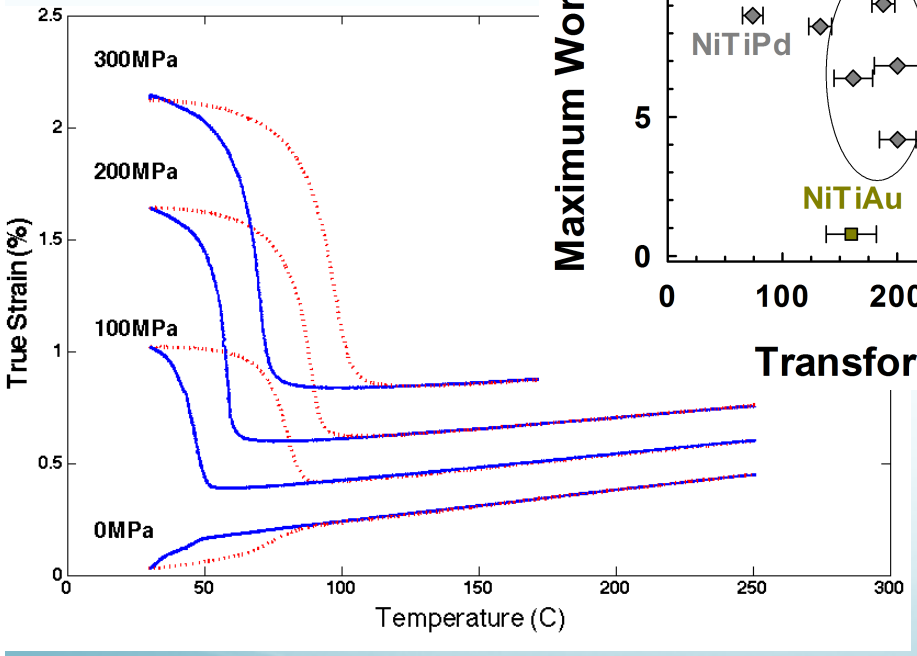
- High temperature shape memory alloys (HTSMAs) formed by alloying with Au, Hf, Pd, Pt, or Zr.
- Ni-rich alloys: stability, bandwidth
- Tf Temps drop drastically with Ni content for Ni-rich alloys
- Compositional control with such precision is difficult
- Aging can be used to regain Tf temps.
- M_S: Martensite Start, M_P: Martensite Peak

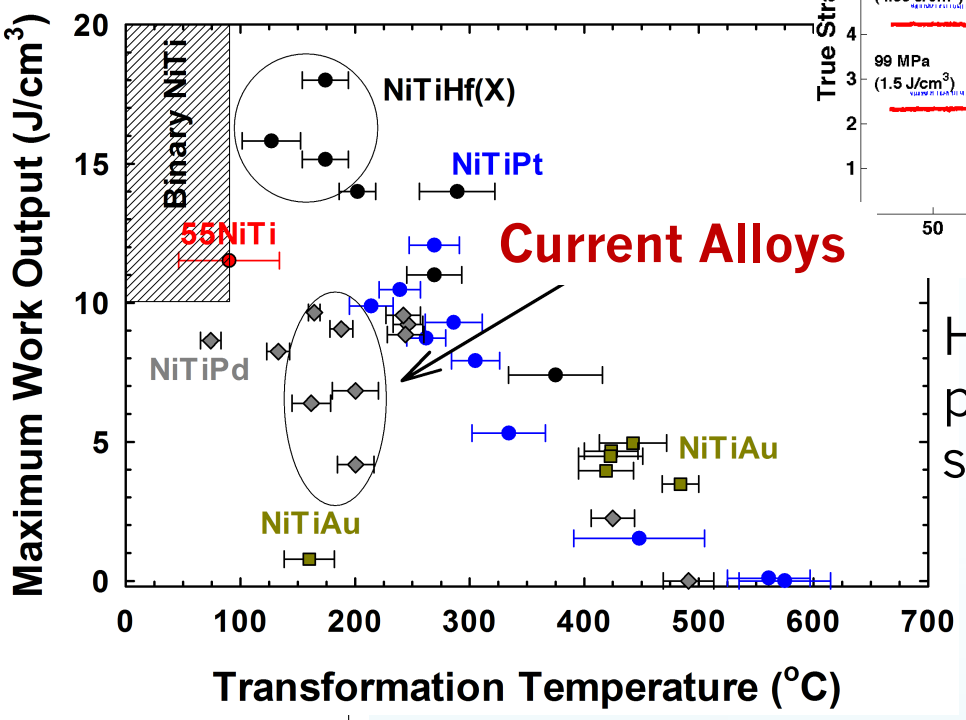


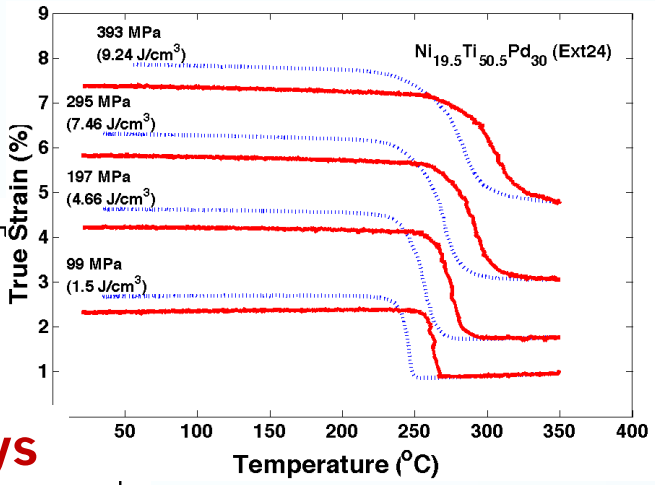
NiTi - F. Sczerzenie, Proc of SMST 2004

Prior State of the Art

Low Temp, Ni-rich, dimensionally stable
Very high ppt volume







High Temp, Ti-rich, poor dimensional stability

*** Need to optimize chemistry and precipitation to achieve high temp (~200°C) alloy with good work output**

NiTi - F. Sczerzenie, Proc of SMST 2004

Approach

- Produce range of alloys having target Ti contents of 50.5, 49.7, and 49.2 at%
  - Vacuum Induction Melting (VIM) in graphite crucible
- Age samples at various times and temperatures
- Determine microstructure as extruded and aged
- Load biased test in tension in series w/2 cycles per stress (MPa) level:
  - No-load, 50, 100, 200, 300, 400MPa, No-load
- Load biased cycle temperatures:
  - Ext 181: (50.5Ti) 30°C to 400C
  - Ext 182: (49.7Ti) 30C to 350C
  - Ext 183: (49.2Ti) 30C to 350C
- Determine effect of aging on actuator type properties

http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

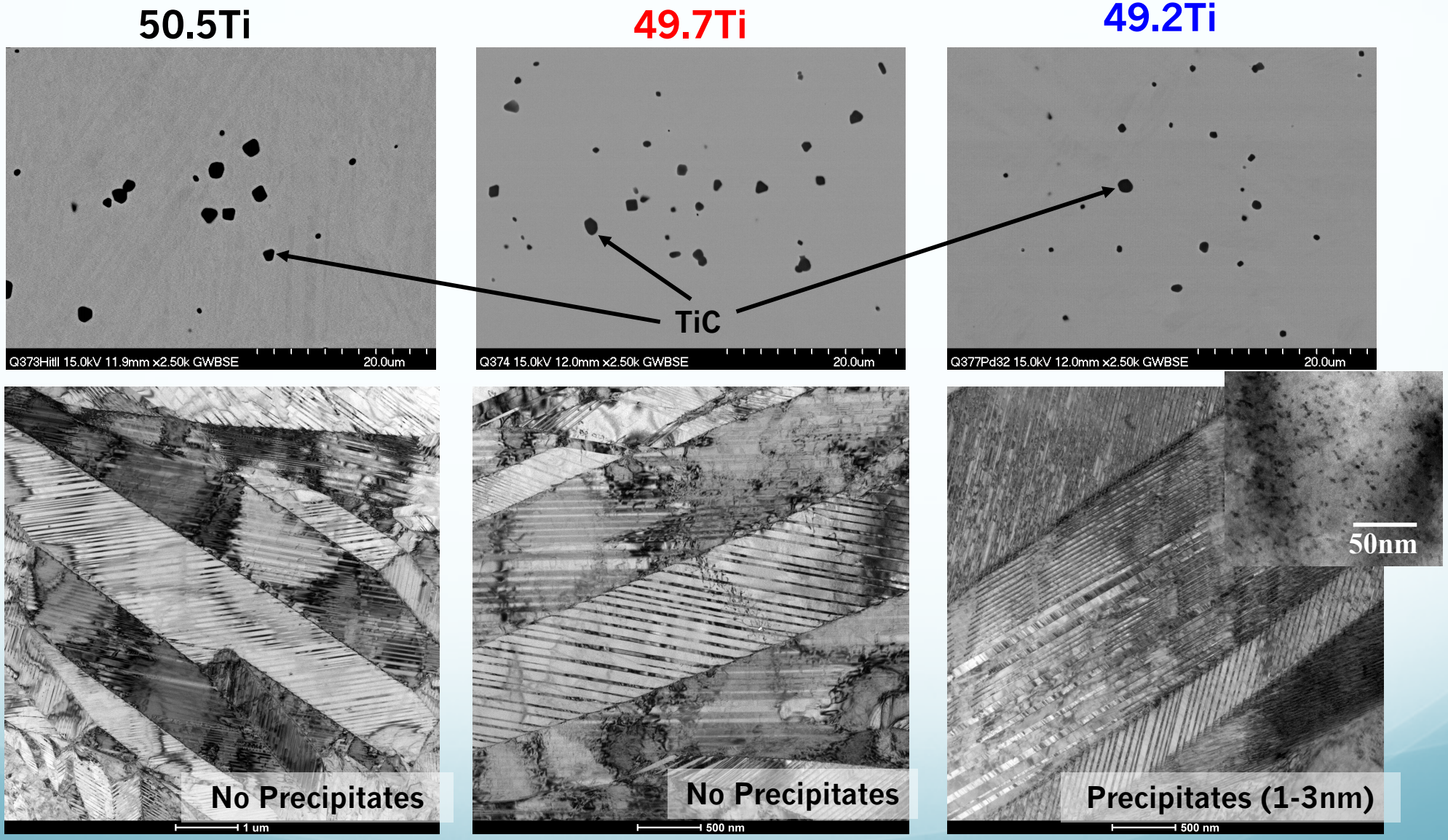
Compositions and Heat Treats

Ext 181	Ext 182	Ext 183
$Ti_{50.5}Ni_{17.5}Pd_{32}$	$Ti_{49.7}Ni_{18.3}Pd_{32}$	$Ti_{49.2}Ni_{18.8}Pd_{32}$
As Extruded	As Extruded	As Extruded
	350C/24hr/AC*	350C/24hr/AC*
	350C/66hr/AC	350C/66hr/AC
350C/100hr/AC	350C/100hr/AC	350C/100hr/AC
	400C/24hr/AC*	400C/24hr/AC*
400C/52hr/AC	400C/52hr/AC	400C/52hr/AC
	450C/24hr/AC	450C/24hr/AC

*Solutionized 1050C/24hr/WQ before aging.

http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

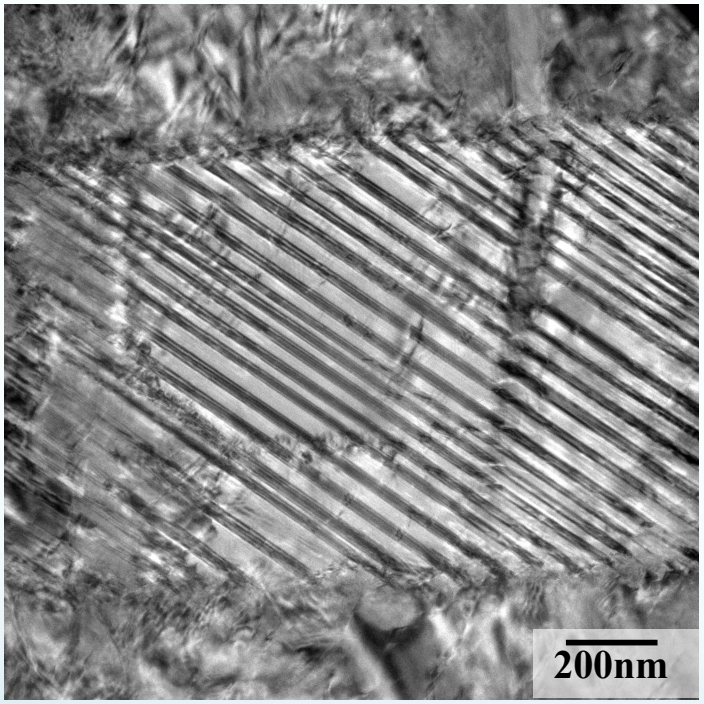
Microstructure: As Extruded



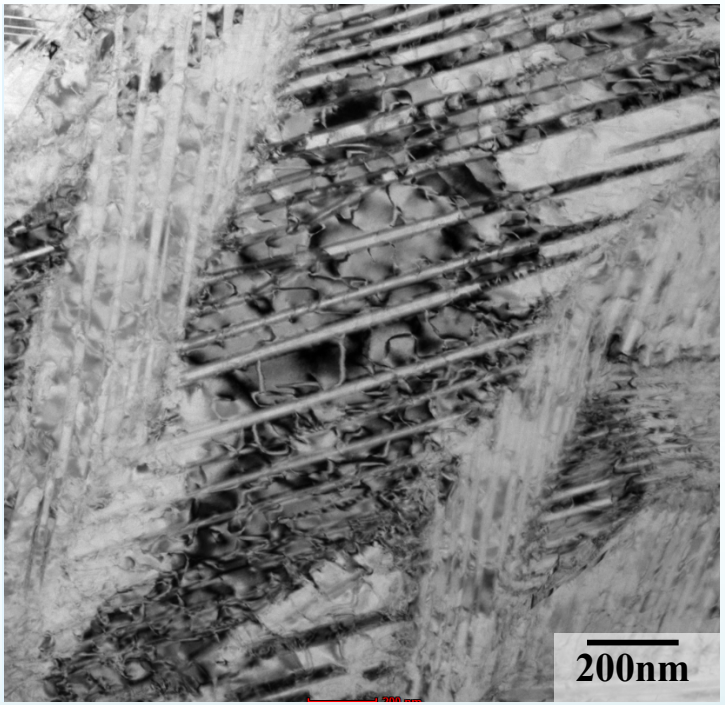
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Microstructure: 50.5Ti

As Extruded



350C/100hr



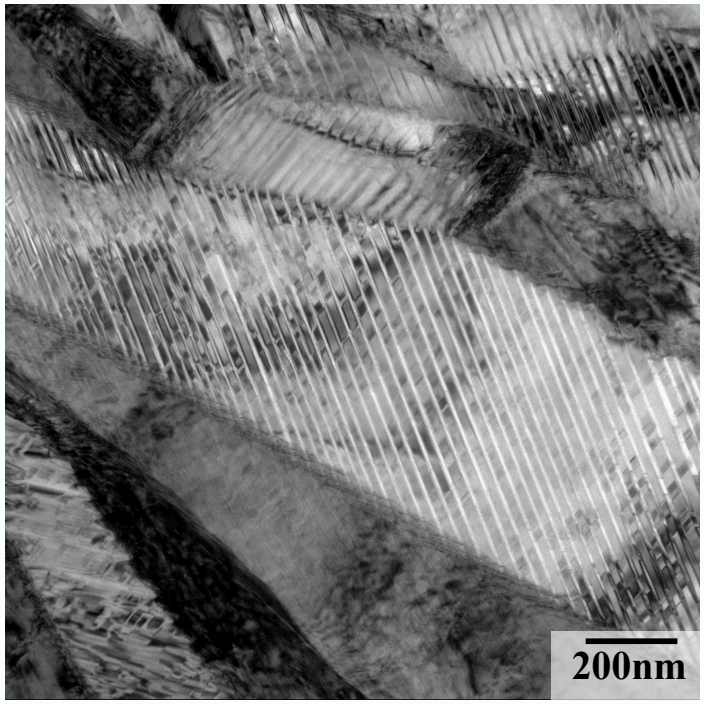
Ti rich: No Precipitates

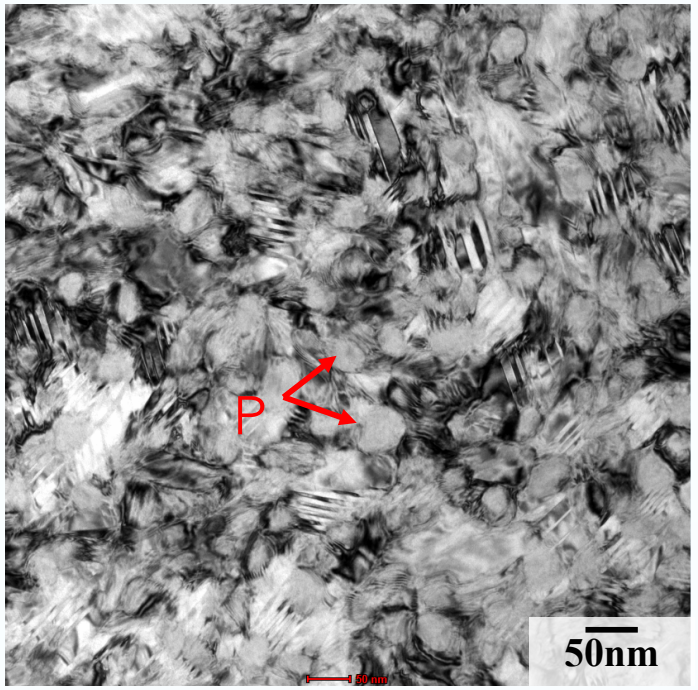
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Microstructure: 49.7Ti

As-Ext

No Ppts.



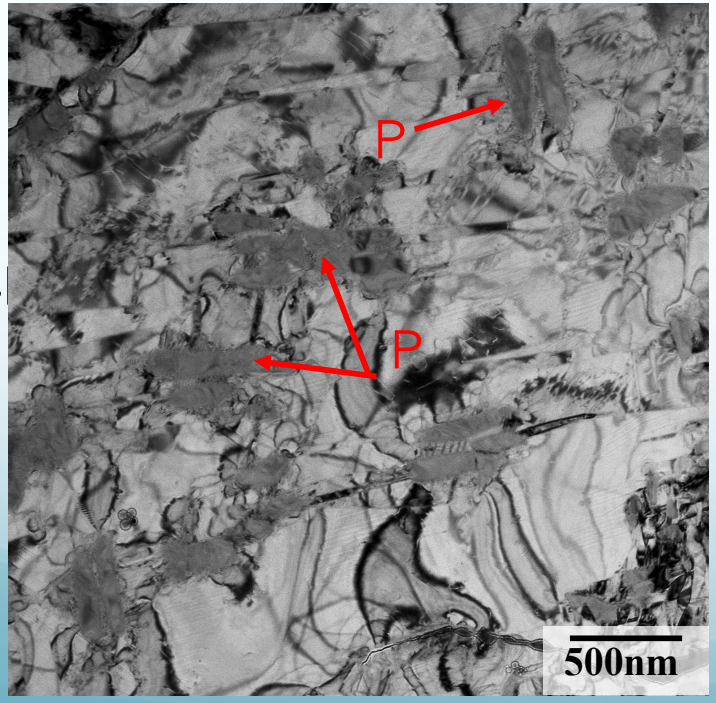


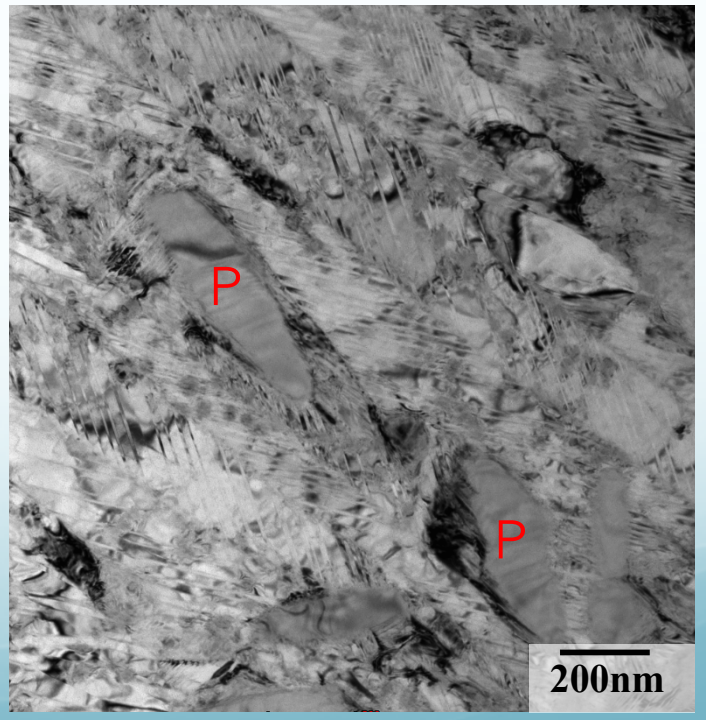
350C/66h

Ppts.
Av. Size
~ 50nm

400C/24

Ppts.
Av. Size
~ 400nm





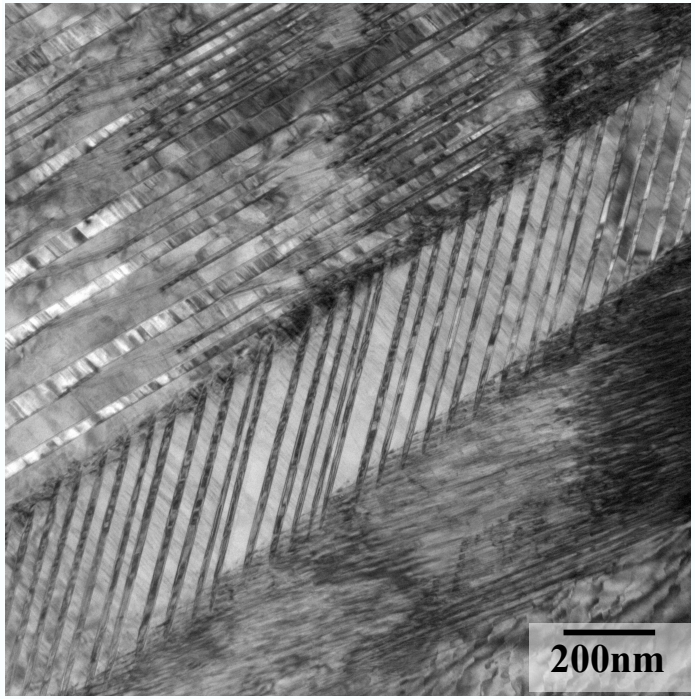
450C/24h

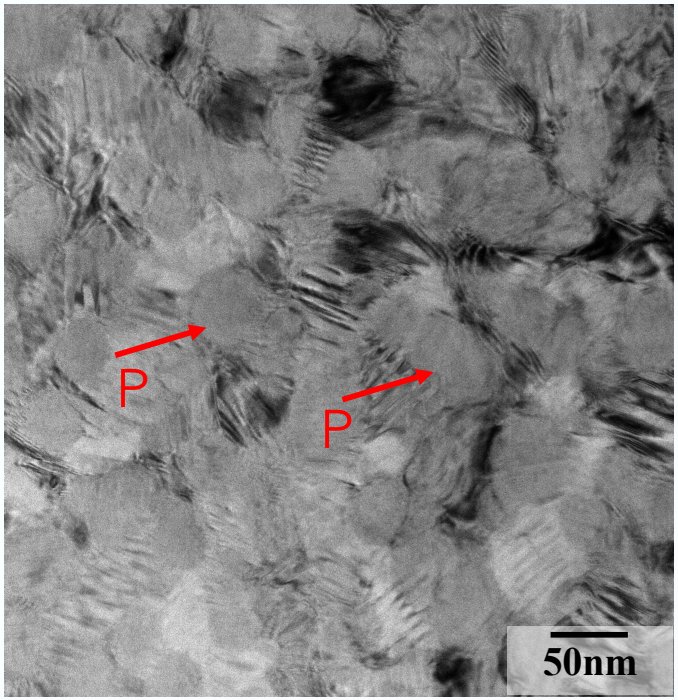
Ppts.
Av. Size
~ 500nm

Microstructure: 49.2Ti

As-Ext

Ppts.
Av. Size
~ 2nm



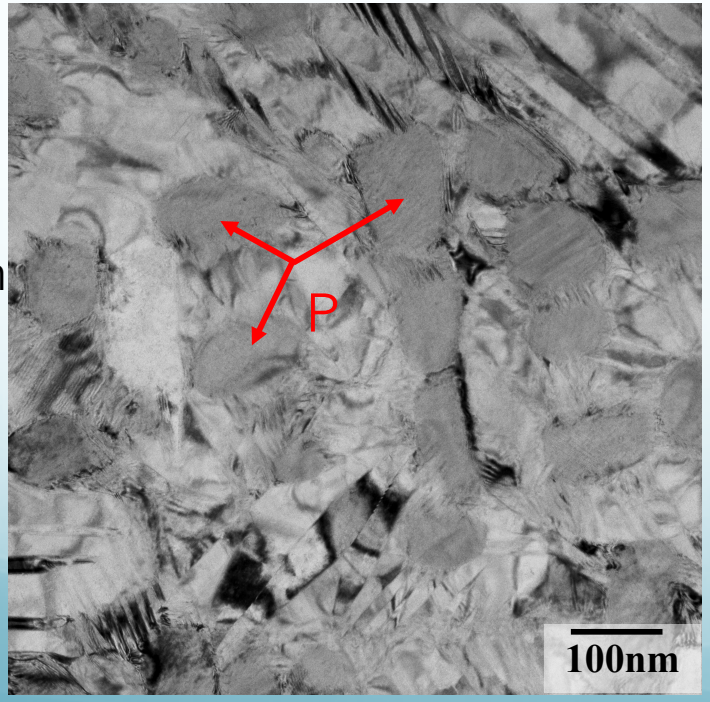


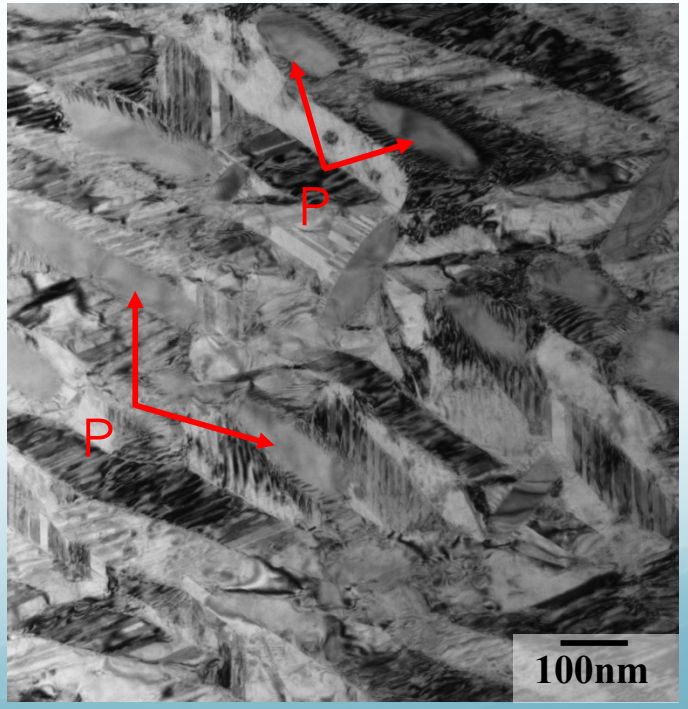
350C/66h

Ppts.
Av. Size
~ 60nm

400C/24h

Ppts.
Av. Size
~ 120nm

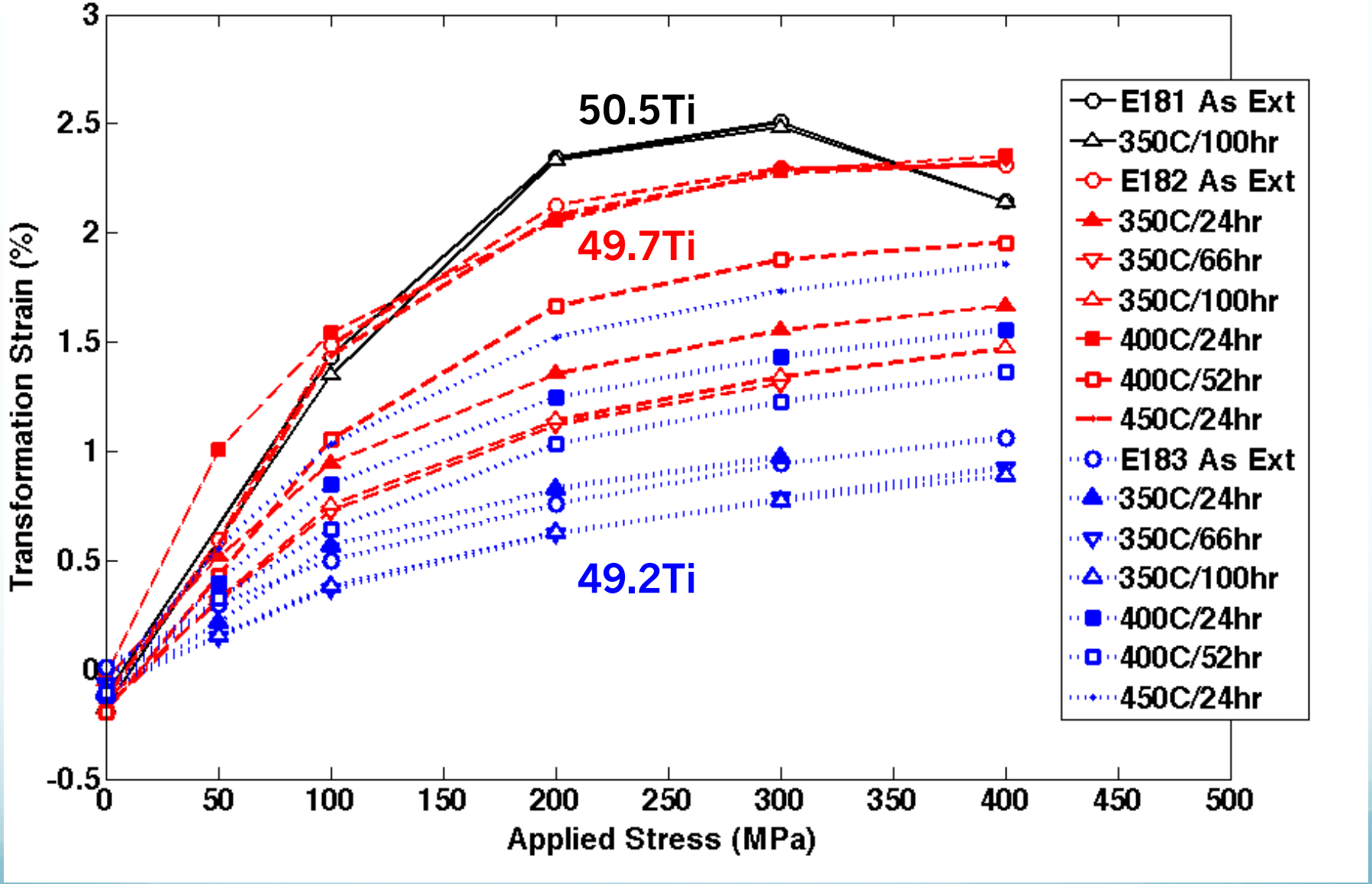




450C/24h

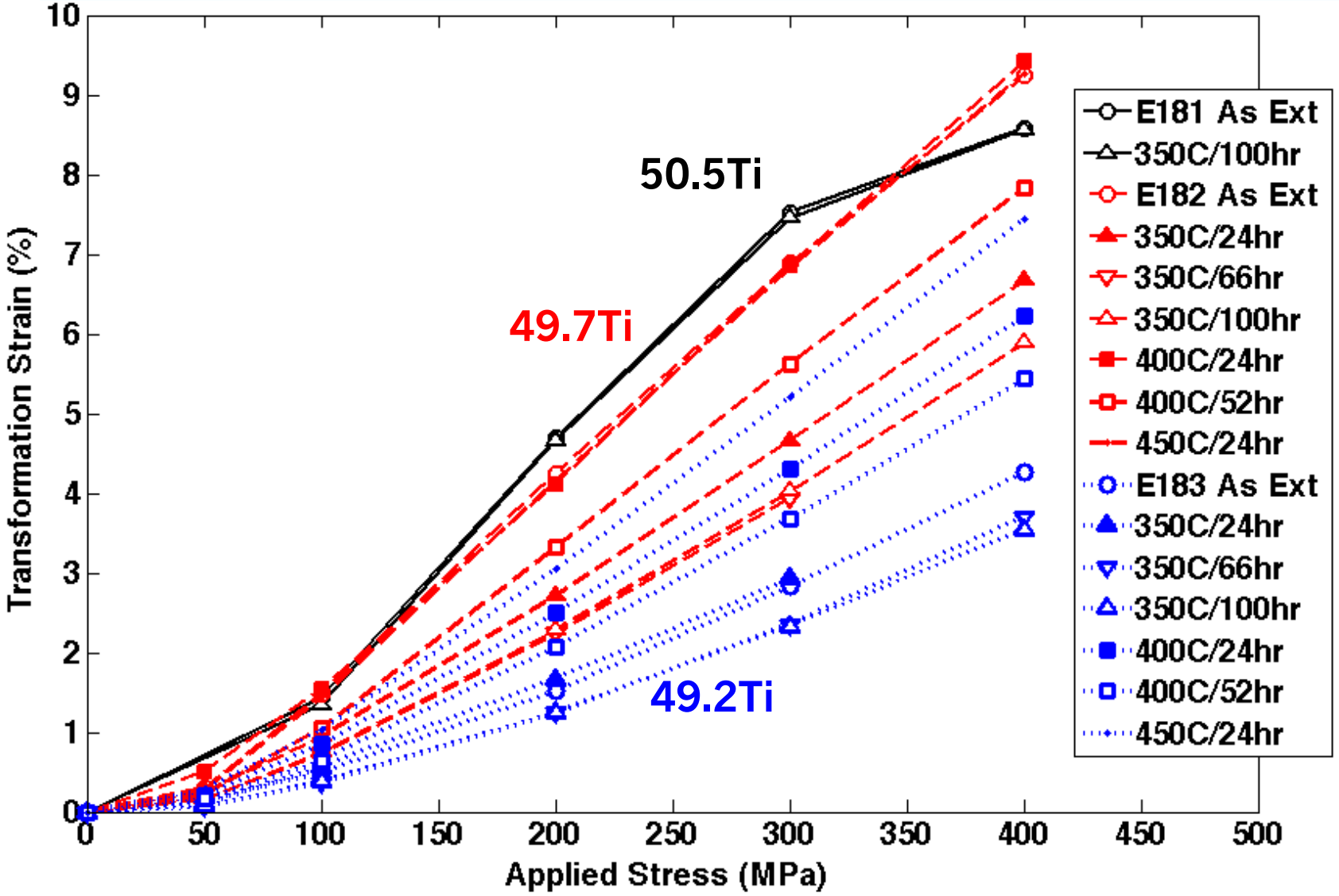
Ppts.
Av. Size
~ 250nm

Transformation Strain



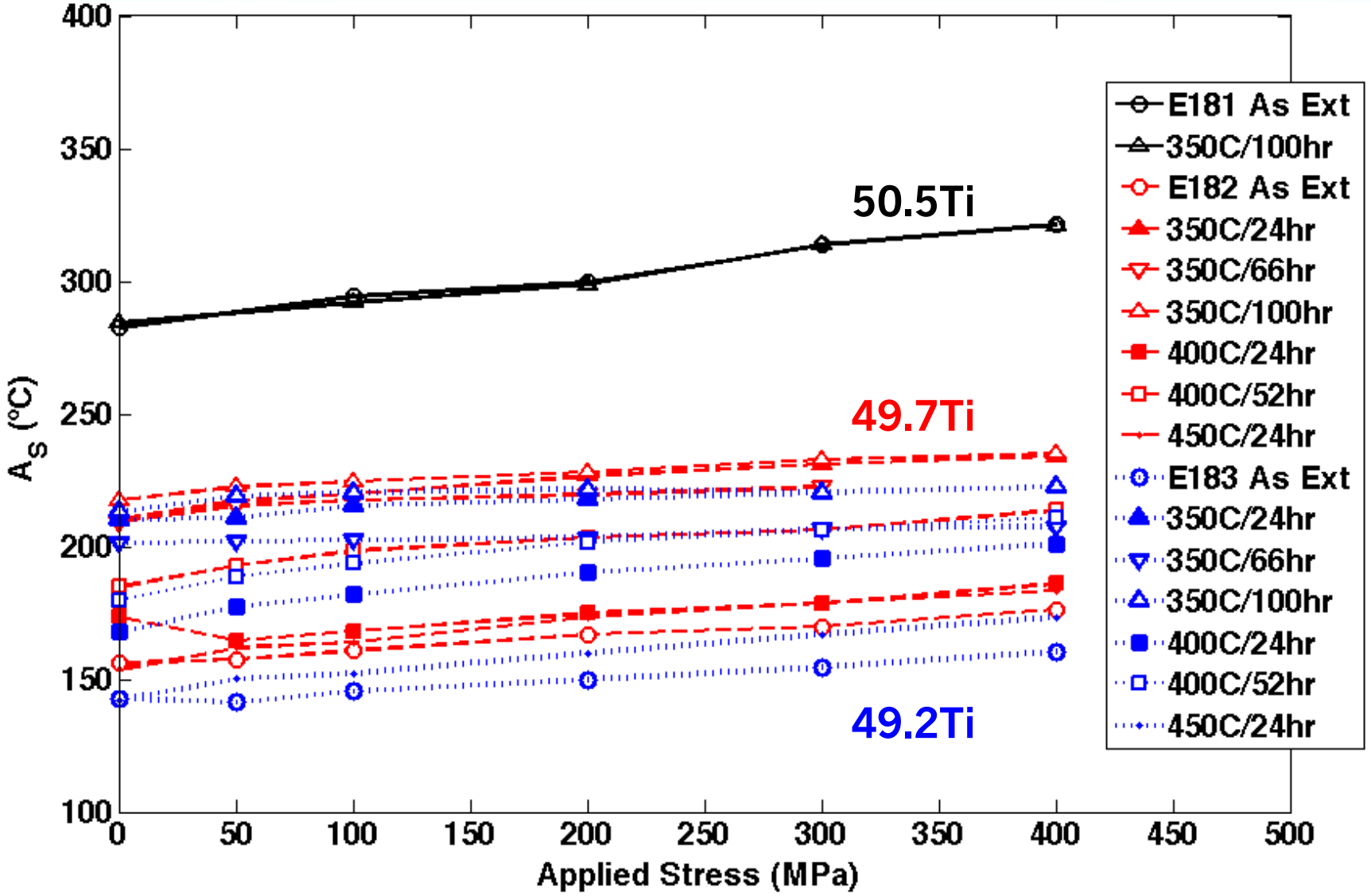
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Work Output



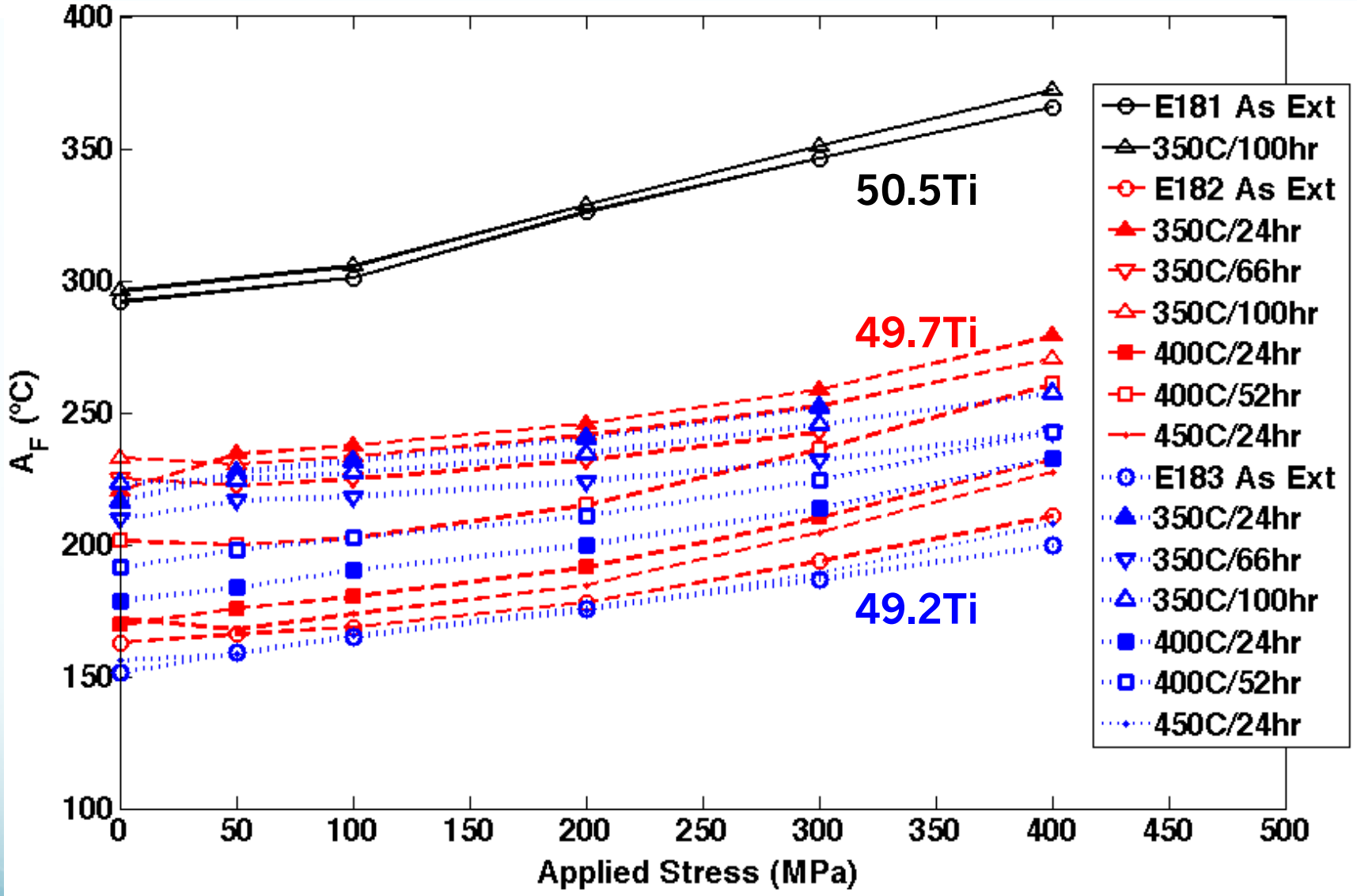
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Austenite Start



http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Austenite Finish



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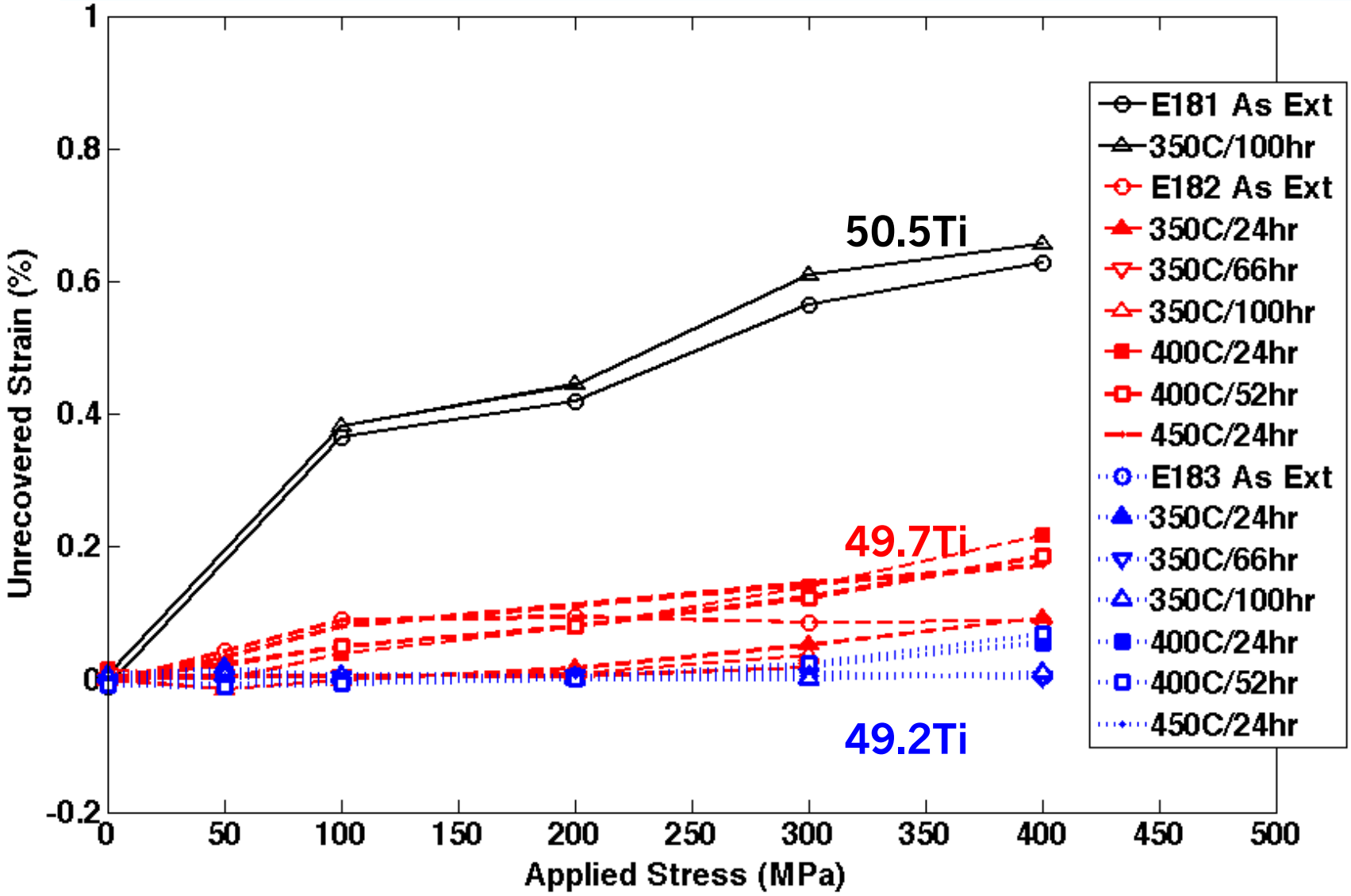
Unrecovered Strain



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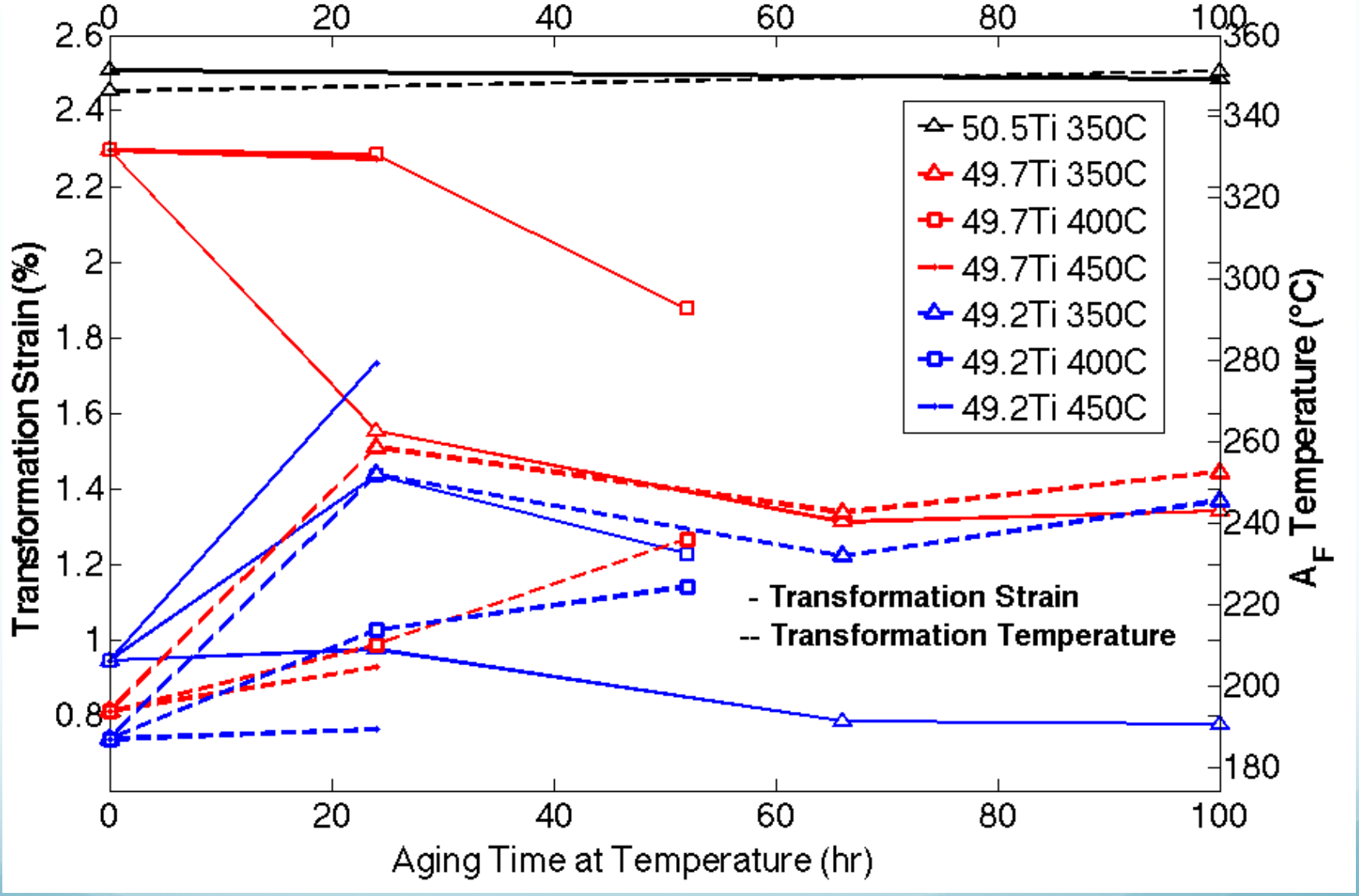
Optimization of Properties

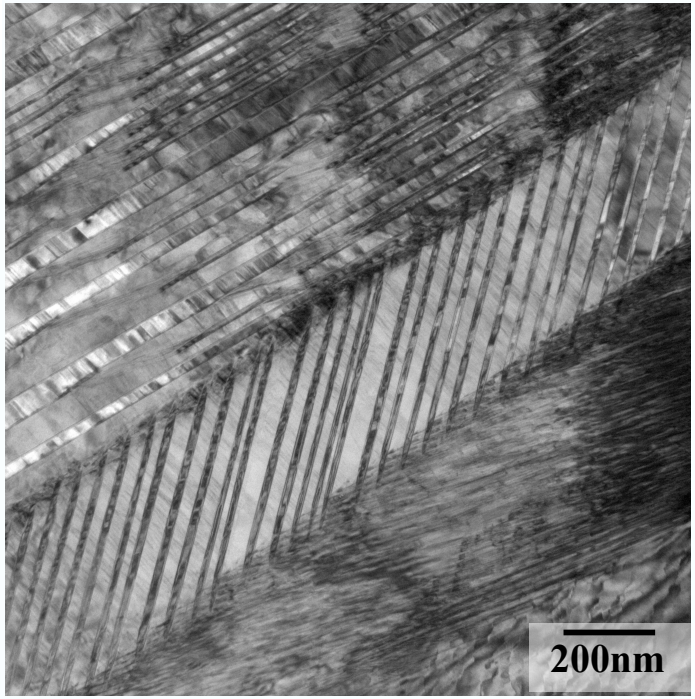


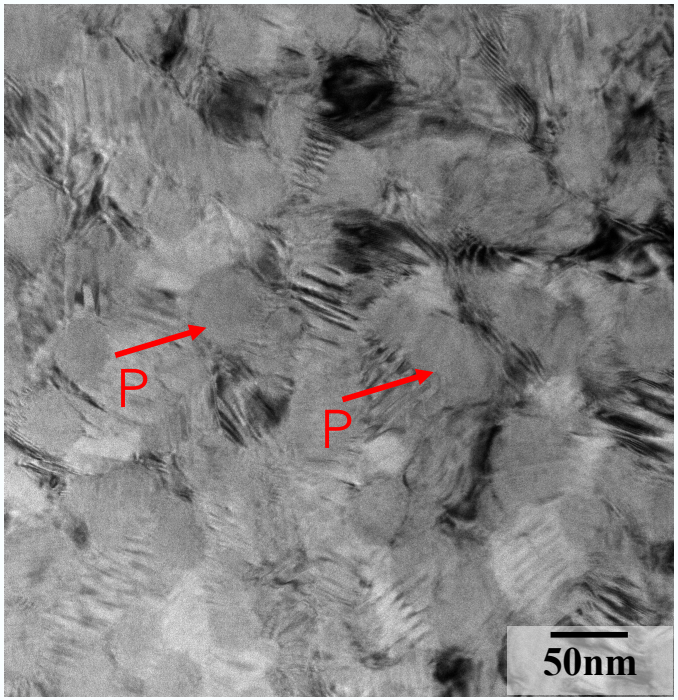
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Microstructure: 49.2Ti

As-Ext

Ppts.
Av. Size
~ 2nm



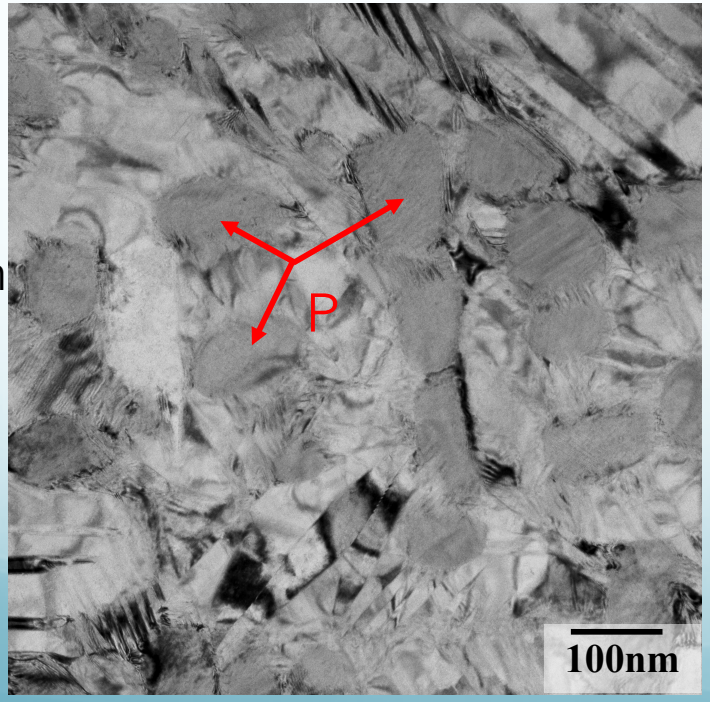


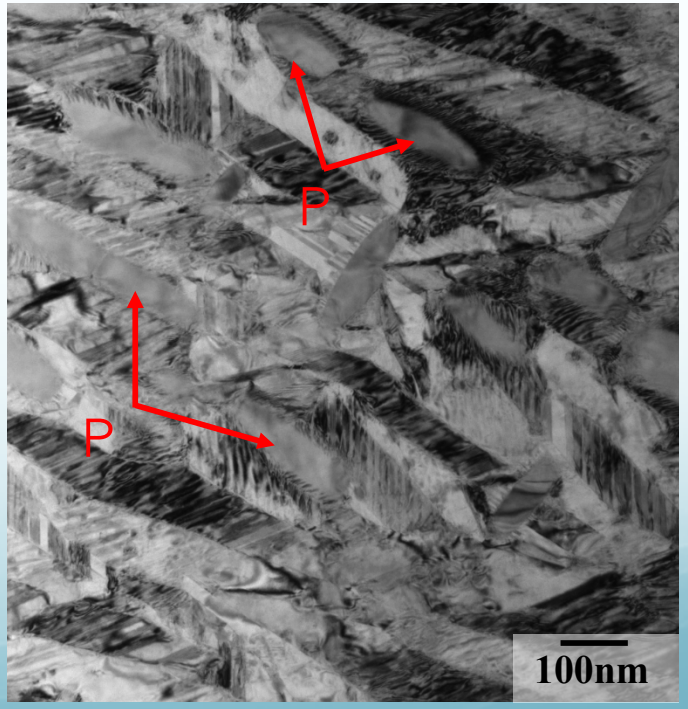
350C/66h

Ppts.
Av. Size
~ 60nm

400C/24h

Ppts.
Av. Size
~ 120nm

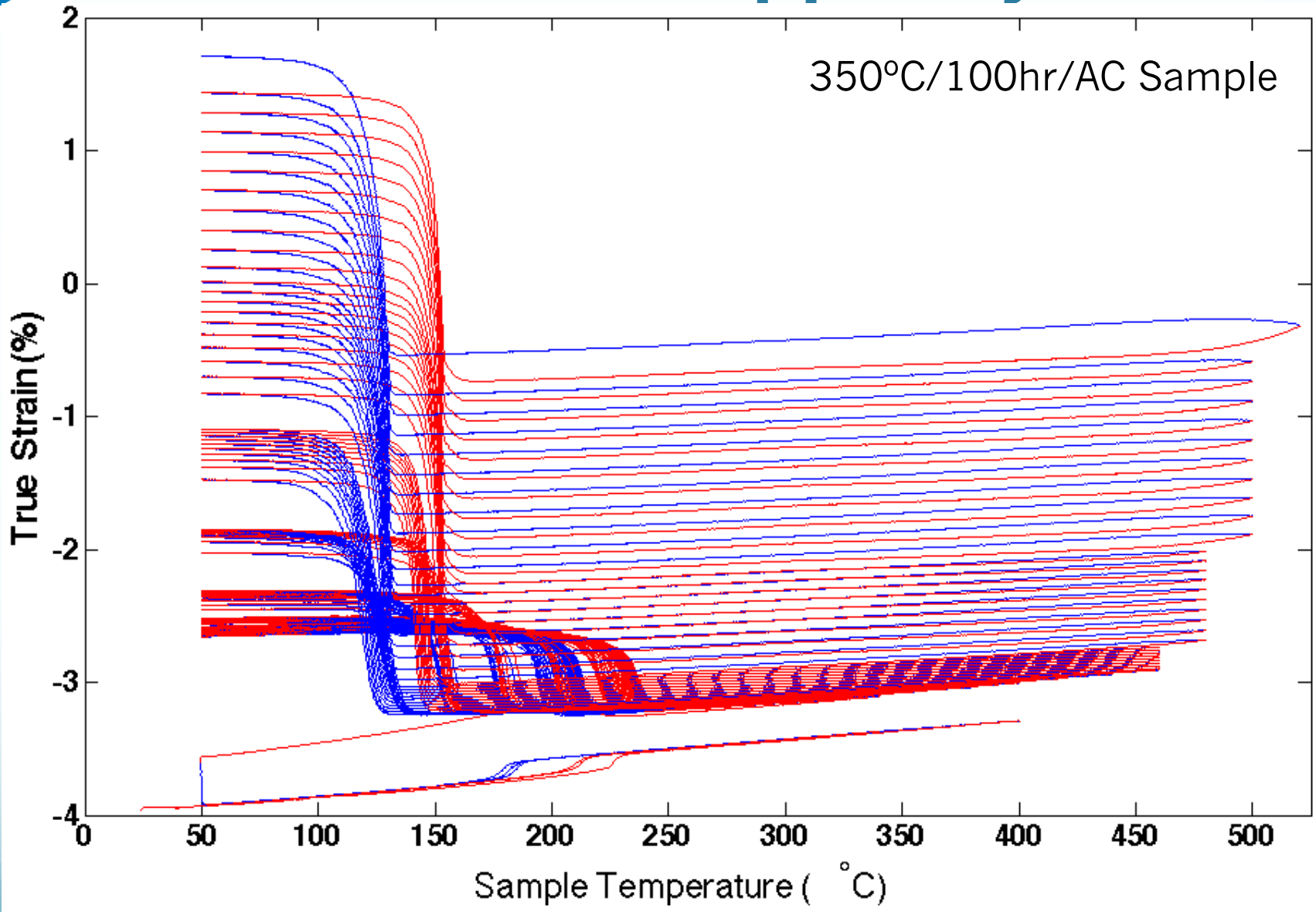




450C/24h

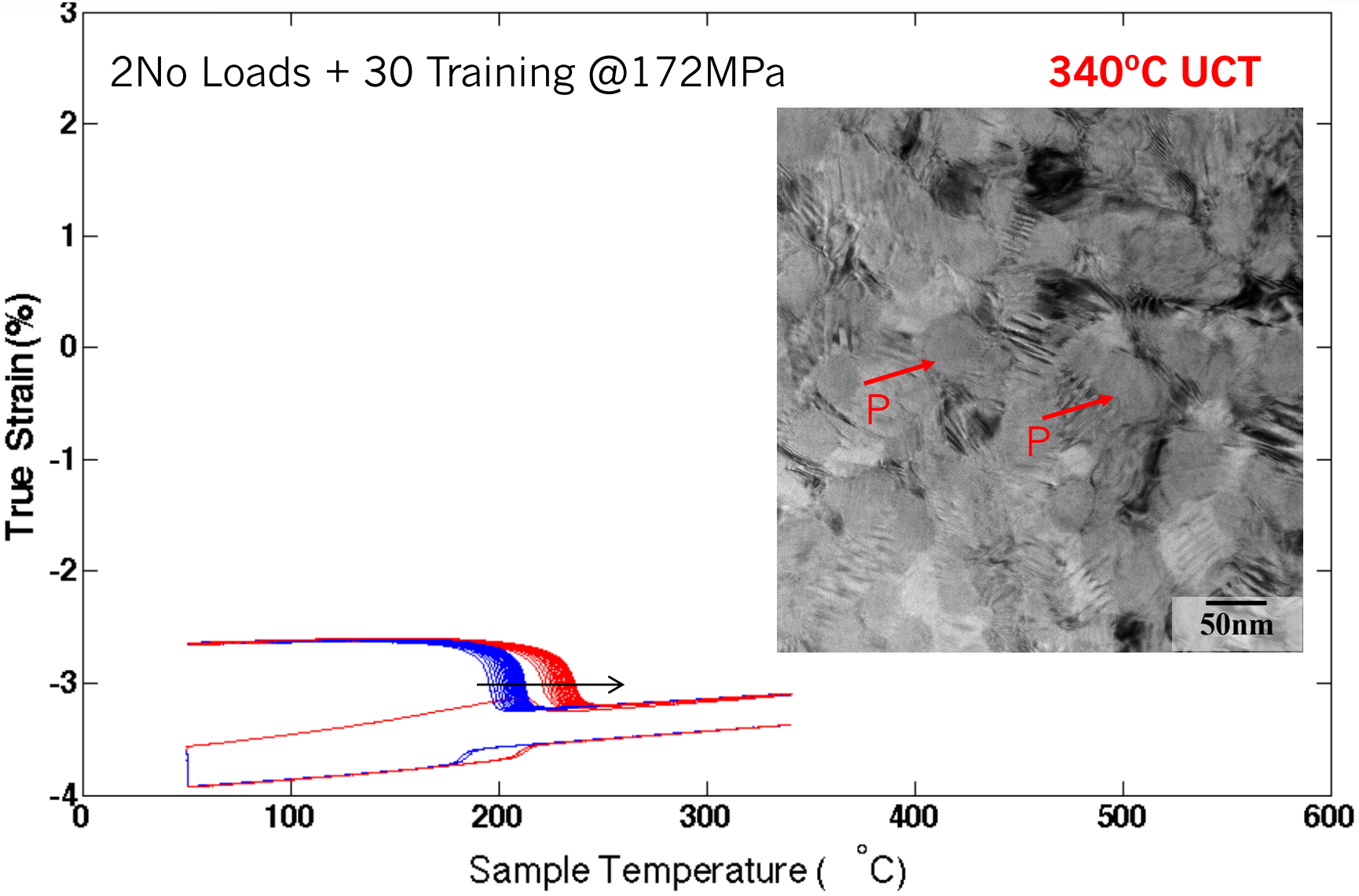
Ppts.
Av. Size
~ 250nm

49.2Ti Dynamic Creep Overview: Shows Effect of Upper Cycle Temp



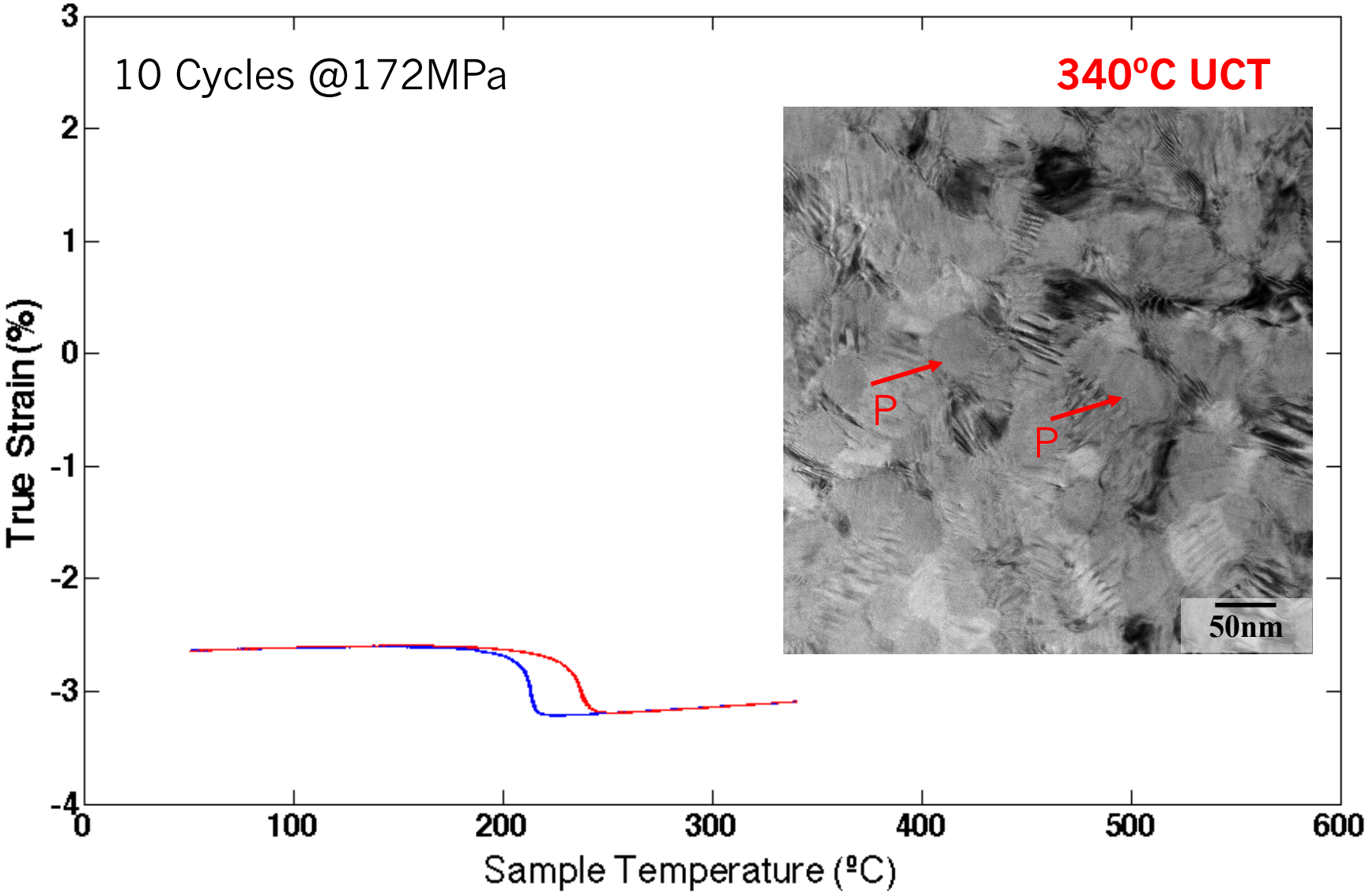
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

340ºC UCT Training Increases Transformation Temperature



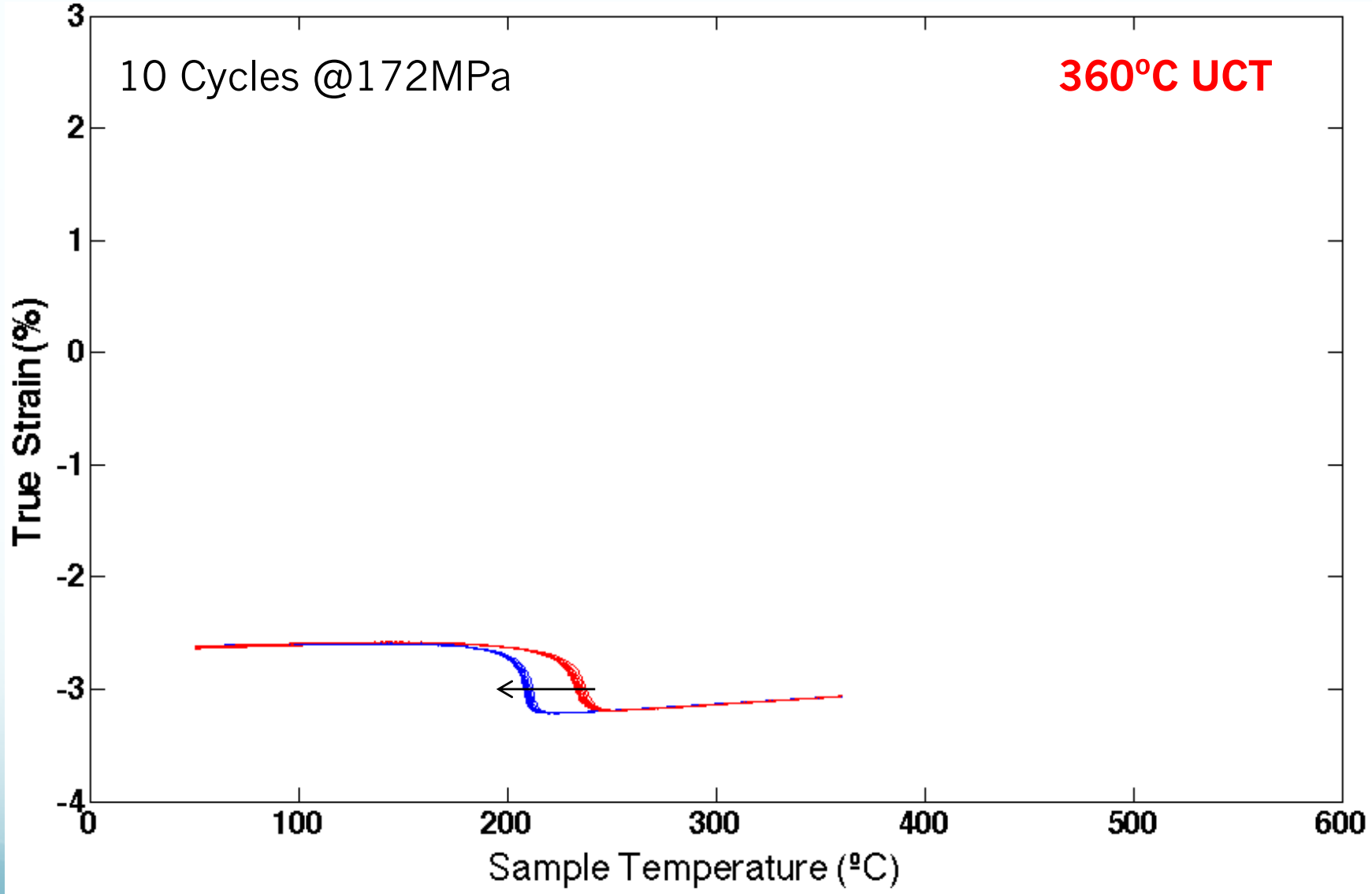
http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

After Training Cycles, Transformation is Stable



http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

$Ti_{49.2}Ni_{18.8}Pd_{32}$ 350C/100hr



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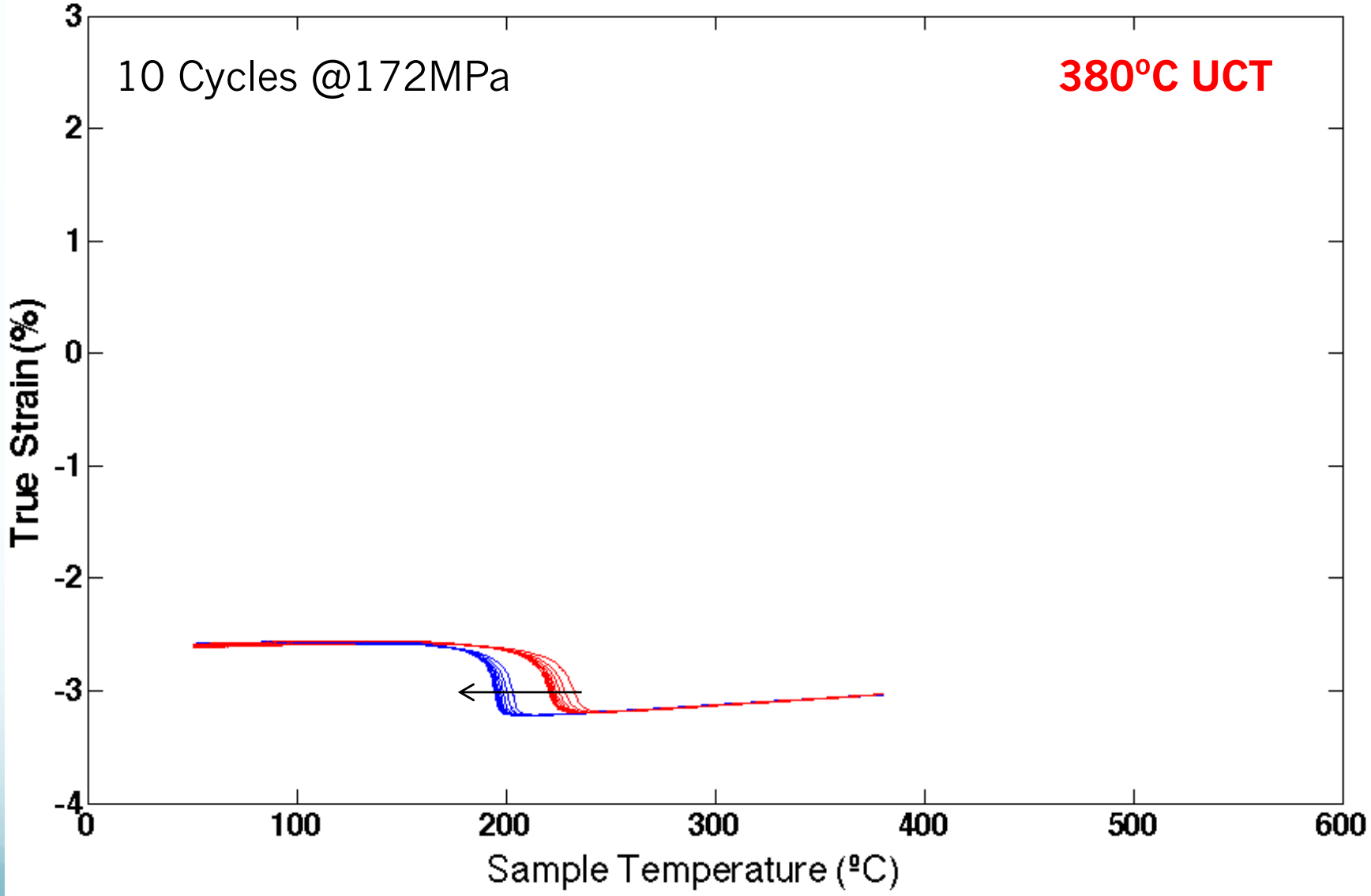
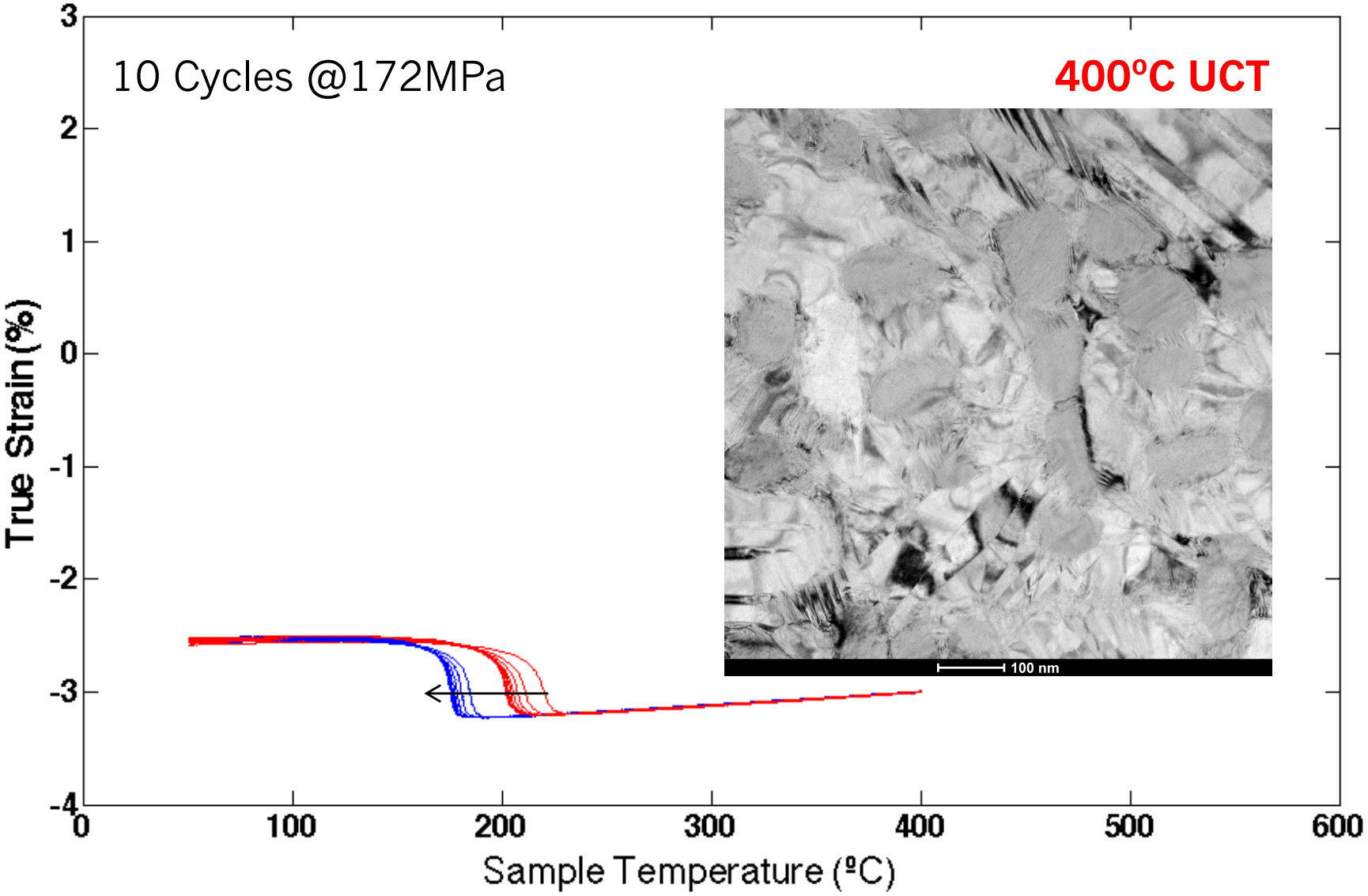
$Ti_{49.2}Ni_{18.8}Pd_{32}$ 350C/100hr



http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Precipitates Coarsen/Grow



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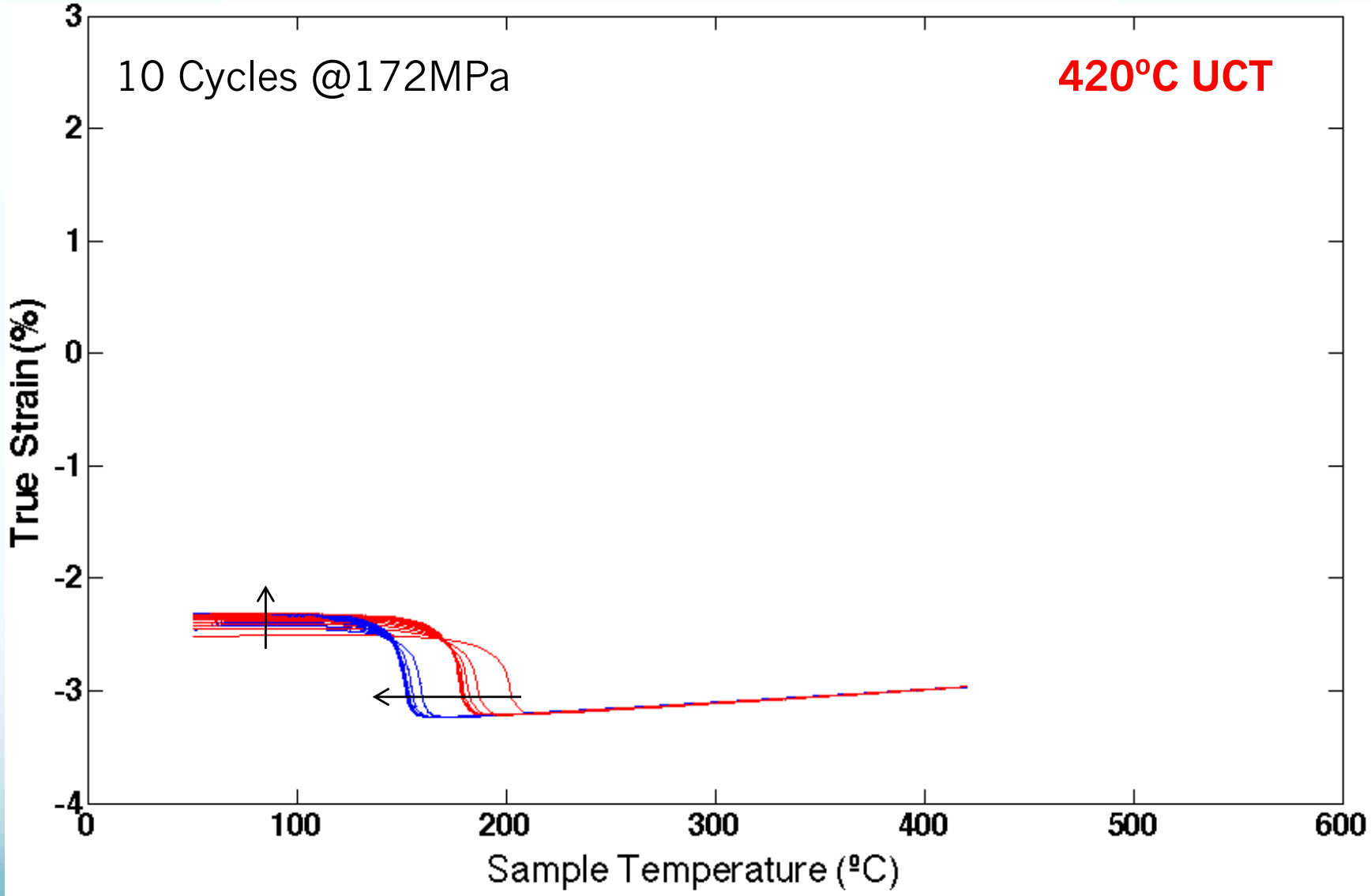
Precipitates Grow Faster



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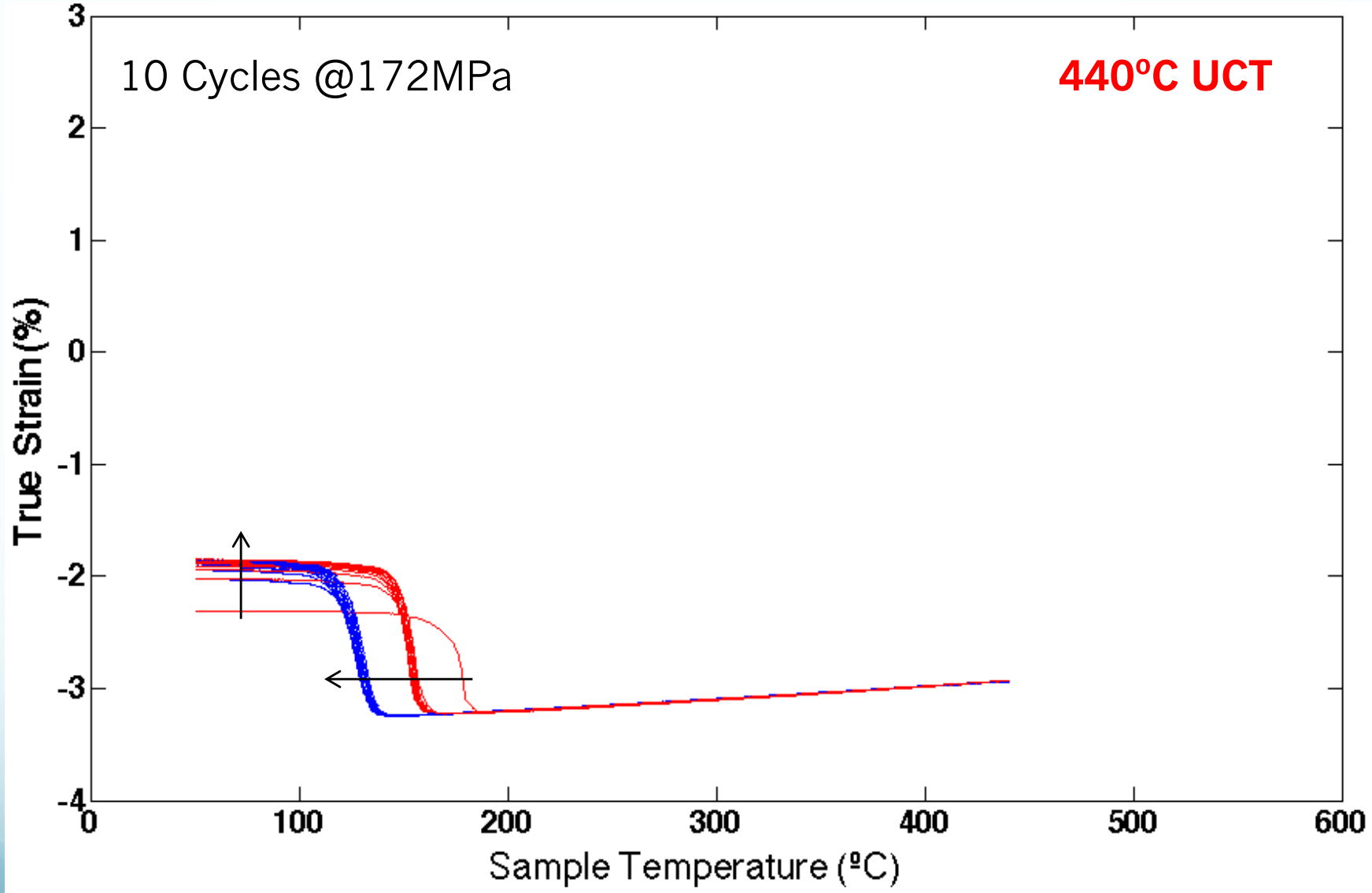
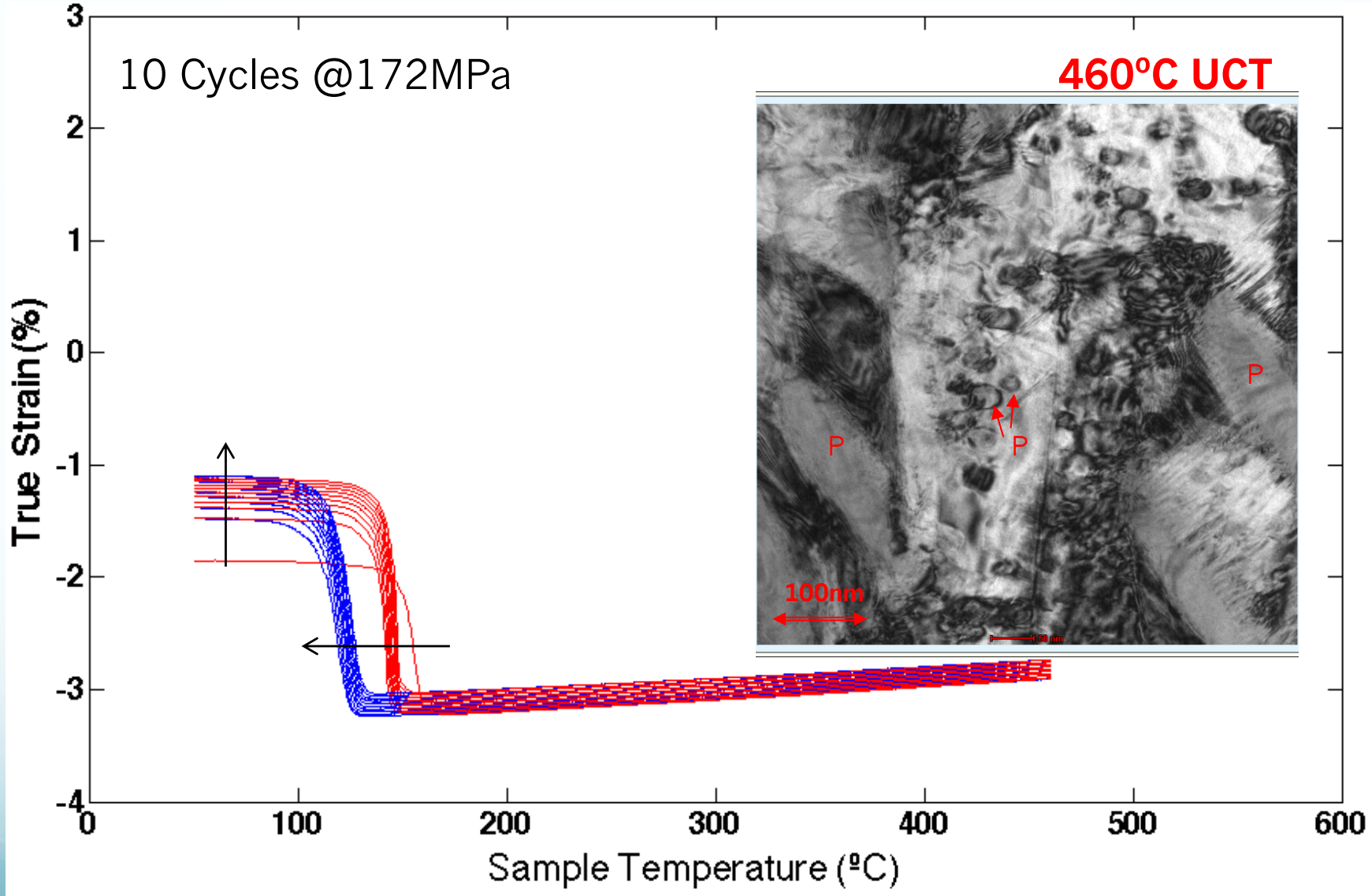
Precipitates Grow Faster



http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Aging Continues To Decrease Transformation Temp



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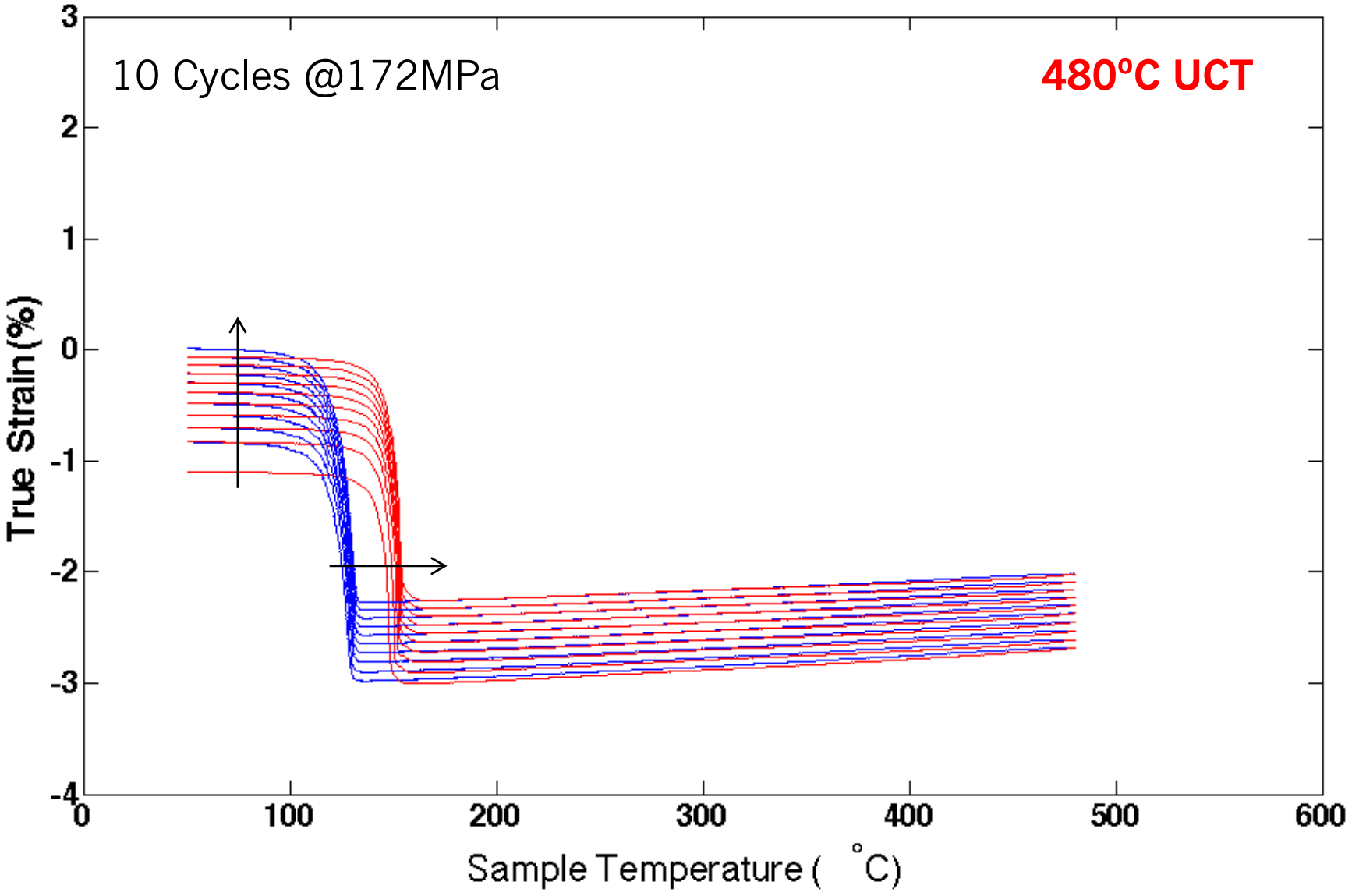
Dynamic Creep Begins



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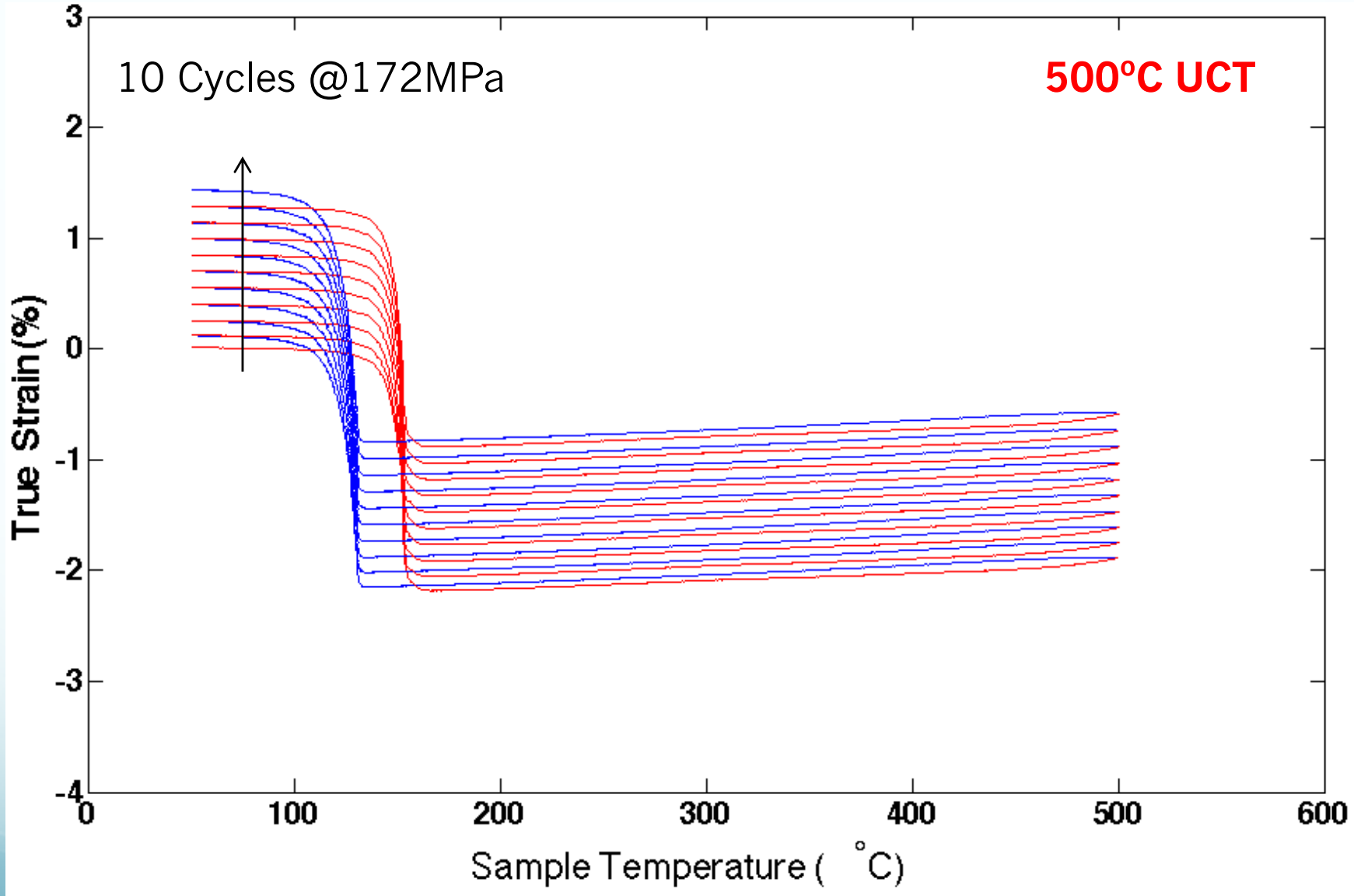
Dynamic Creep Dominates



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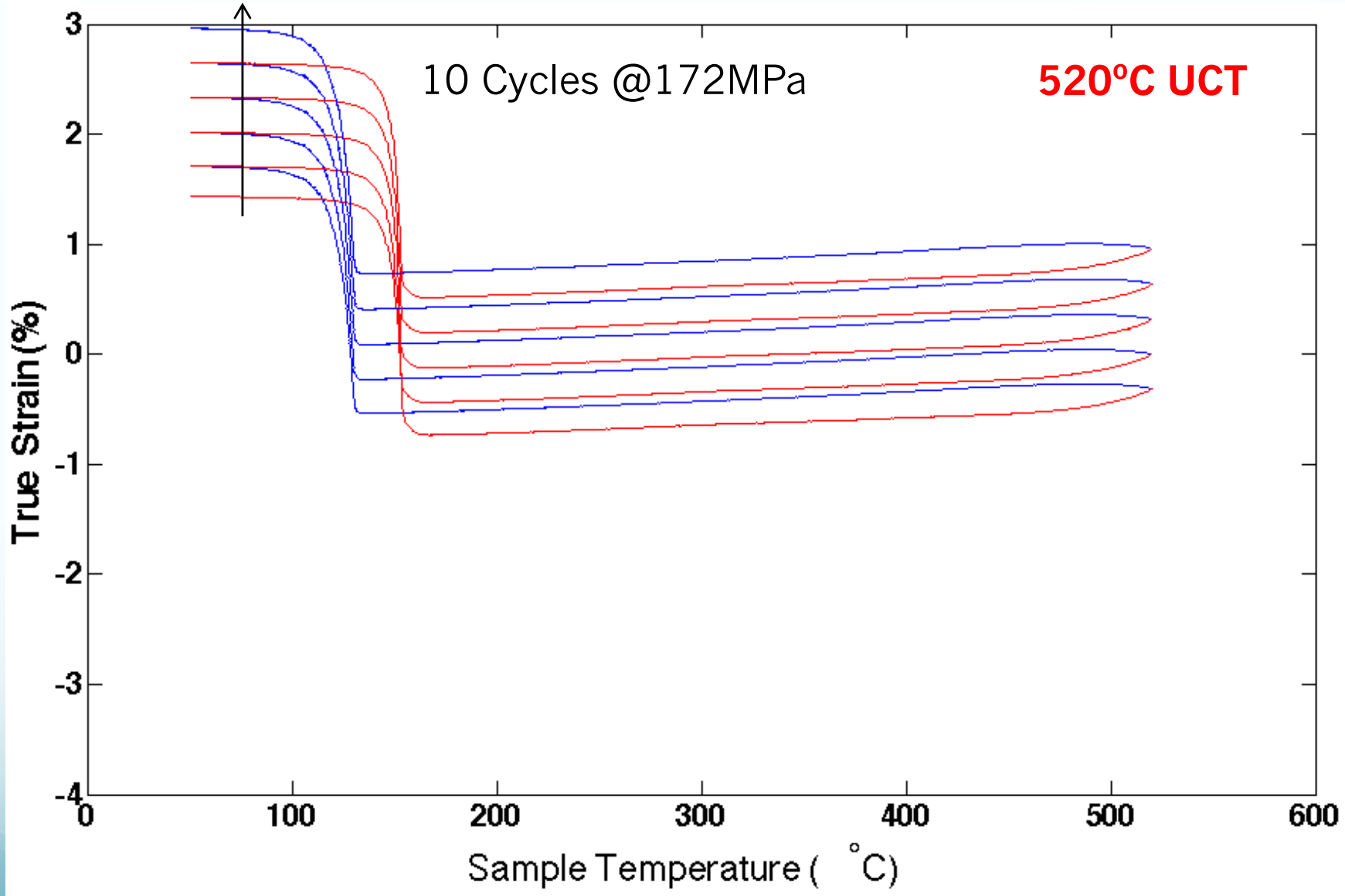
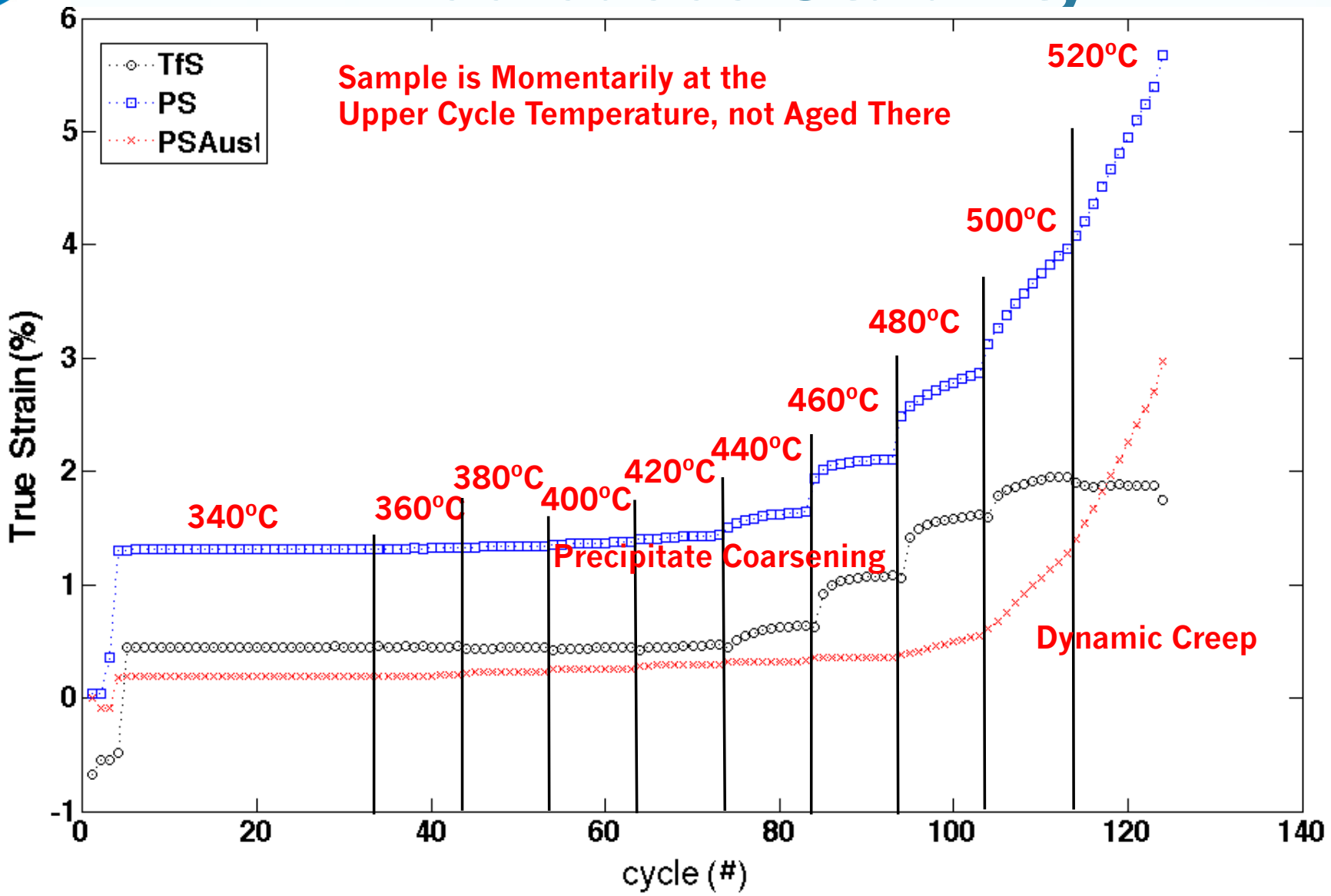
Dynamic Creep Dominates



http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html

Higher UCT: Increases Tf Strain, Decreases Stability



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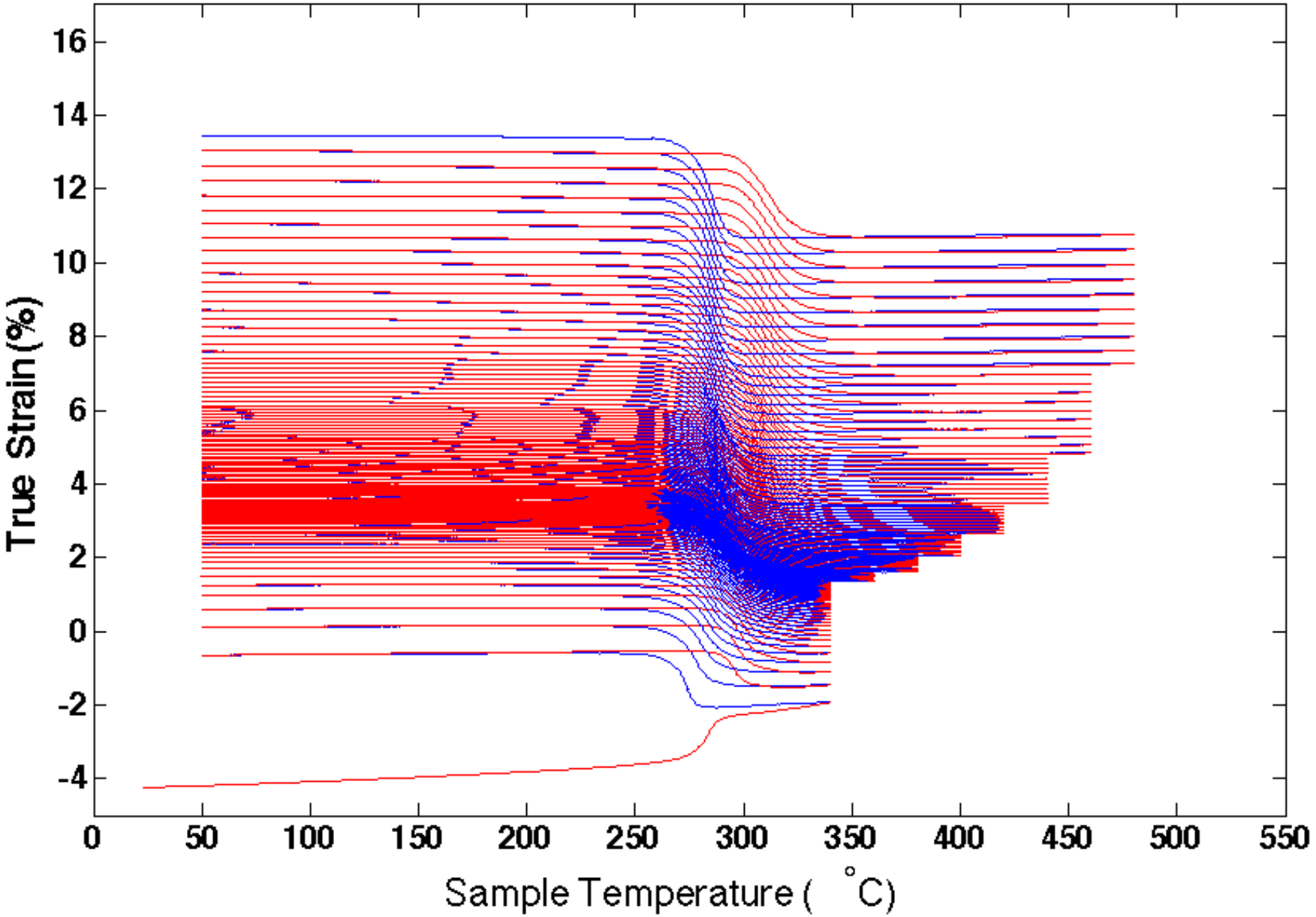
Ti Rich Material: Tf Temps Don't Change



http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/Research/shape_memory.html

Conclusions

1. Decreasing Ti content
    1. Increases second phase content
    2. Decreases Tf Temp
    3. Decreases Work Output
    4. Improves Dimensional Stability
2. Aging Time/Temp Effects:
    1. Low Temp

       Small ppts – increase Tf Temp, decrease Tf Strain
    2. High Temp

       Large ppts – decrease Tf Temp, increase Tf Strain
3. Optimum Transformation Strain & Temp
    1. Low Temp (350°C) aging for short times
    2. Moderate Temp (400°C) aging for longer times
        1. Higher Unrecovered Strain